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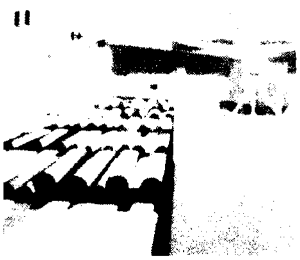

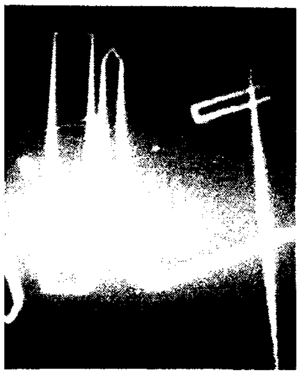

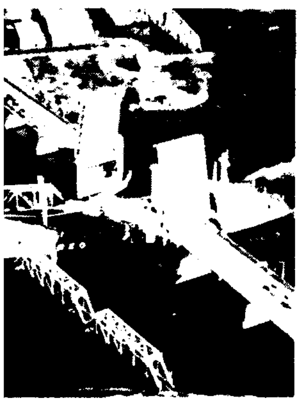

HYDRAULICS
LABORATORY

(2)

TECHNICAL REPORT HL-91-18

SHIP SIMULATION STUDY OF GRAYS HARBOR NAVIGATION PROJECT, GRAYS HARBOR, WASHINGTON

by

J. Christopher Hewlett, Kathren M. Eagles
Carl J. Huval, Larry L. Daggett

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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J. Christopher Hewlett
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13. ABSTRACT *(Maximum 200 words)*

Grays Harbor is a log exporting port on the coast of Washington. The harbor comprises an outer region, which crosses the bay section of Grays Harbor, and the inner section, which follows the Chehalis River. The navigation channel presently can accommodate lumber ships only up to 85 ft in beam and 34 ft in draft because of the very constricted railroad and highway bridge spans that cross the inner part of the harbor. Local economic interests desire to bring wider and deeper lumber ships into the harbor. To accommodate this change, the US Army Engineer District, Seattle, recommended widening and deepening the channel to allow ships up to 100 ft in width and 36.5 ft in draft. The existing 125-ft navigation span through the bridges is to be increased to 185 ft by replacing the railroad bridge with a new design. The proposed changes also call for the construction of a new turning basin at the upstream end of the deepwater project.

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This report presents results of numerous ship simulation tests in the inner as well as the outer region of the harbor. The primary navigation difficulties experienced by the pilots were the outer region bends and the inner region sharp turns and bridge passage.

The study concluded that the channel width in the outer region can be maintained at its existing 350 ft and does not require widening to the proposed 400 ft. Bend wideners were required on the outside of the bends where it is already deep to compensate for the tendency of the pilots to drift out of the channel with the larger proposed ship. In the inner region, the study showed that the larger ships could safely make the transit through the proposed bridge span and turn around in the proposed turning basin, resulting in increased project benefits. Some modifications to the District proposed channel are presented.

PREFACE

This investigation was performed by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, Seattle (NPS). The study was conducted with the WES research ship simulator. The study was conducted during the period August 1985–December 1986. The study results were provided to NPS by means of letter reports in December 1986 and March 1987 for the outer and the inner region, respectively.

The investigation was conducted by Messrs. Carl J. Huval and J. Christopher Hewlett and Ms. Kathren M. Eagles with the help and support of Dr. Larry L. Daggett under the general supervision of Mr. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory; Richard A. Sager, Assistant Chief, Hydraulics Laboratory; and Marden B. Boyd, Chief of the former Hydraulic Analysis Division, since reorganized into the Waterways Division. This report was edited by Ms. Marsha C. Gay, Information Technology Laboratory, WES.

Dr. James Waller and Mr. A. David Schuldt provided support from NPS during the study period.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609344	kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

SHIP SIMULATION STUDY OF GRAYS HARBOR NAVIGATION PROJECT GRAYS HARBOR, WASHINGTON

PART I: INTRODUCTION

Background

1. The US Army Engineer District, Seattle, has proposed a plan for ship channel improvement in Grays Harbor, Washington. The main purpose of the proposed improvement is to allow larger ships to enter. This is of economic concern for the area. Currently, the largest ship that can safely operate in all of Grays Harbor is 535 ft* long and 85 ft wide with a loaded draft of 34.0 ft rated at 31,000 deadweight tons (dwt). The primary feature of the proposal is deepening of the channel to accommodate the drafts of the larger vessels, i.e., a ship 625 ft long and 100 ft wide with a loaded draft of 36.5 ft rated at 50,000 dwt. Channel widening is also proposed involving bridge modifications and varying widths at different locations along the channel. The Seattle District requested the US Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory to conduct a ship simulation study concerning the effect of the proposed changes on navigation. A medium-size ship was to be included in the testing with an overall length of 585 ft, a beam of 99 ft, and a loaded draft of 35 ft rated at 41,000 dwt. This ship would be used in the event that the larger ship could not be navigated safely with the proposed channel improvements in place. The depth of the project channel was determined by economic considerations; therefore, the overall objective of the simulator investigation was to test the design of the channel widths and alignments. To accomplish the objective, the simulator testing was designed to emulate actual Grays Harbor shipping operations and conditions. Inbound and outbound loading conditions were set, and water depths and currents were chosen to match the conditions occurring during most actual transits. Numerical models of actual Grays Harbor timber ships were used for the testing, and four professional pilots from the area conducted tests on the simulator. Due to the length of the channel and the amount of data involved, the study was

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

separated into two simulations: the outer harbor scenario and the inner harbor scenario. This report will cover the entire study.

2. The Grays Harbor study area is located on the Pacific coast in the State of Washington adjacent to the town of Aberdeen. Figure 1 shows the harbor and its location. Grays Harbor is, for all practical purposes, exclusively a log exporting port. The logs shipped out of the harbor are in rough form and go primarily to the Far East for processing. Grays Harbor is characterized by a narrow deep entrance from the Pacific Ocean opening into a wide shallow bay. The area of concern for the present study begins well inside the ocean entrance at the seaward end of South Reach. From this point, the channel proceeds approximately 19 miles up the Chehalis River generally in an eastwardly direction. The existing channel is authorized to be 350 ft wide (with wideners at the bends) and 30 ft deep below mean lower low water (mllw) from South Reach near harbor mile (HM) 16 to Aberdeen Reach near HM 2. From this point to the end of South Aberdeen Reach near Chehalis river mile (RM) 2, the channel is authorized to be 200 ft wide and 30 ft deep, mllw. Figure 1 shows existing conditions. The 350- by 30-ft channel encompassing South, Crossover, and part of Moon Island Reaches composes the outer harbor simulator scenario (Figure 2). The 200- by 30-ft channel in South Aberdeen and Aberdeen Reaches in the Chehalis River are included in the inner harbor simulator scenario (Figure 3). This area includes a two-bridge passage consisting of the Union Pacific Railroad (UPRR) and US Highway 101 (US 101) bridges at Aberdeen. The remainder of the Grays Harbor shipping channel through Moon Island, Hoquiam, and Cow Point Reaches was not simulated because the District proposal does not call for widening in these areas.

Descriptions and Objectives of Investigations

Outer harbor

3. The outer harbor study area consists of four straight channel segments divided by three channel turns. The turn between Moon Island and Crossover Reaches represents a course change of approximately 37 deg. The other two turns show course changes of approximately 24 and 26 deg, respectively. These three turns together with the narrowness of the channel could pose a navigation problem were it not for two important factors that alleviate the hazards. The first is that the light traffic load in Grays Harbor allows

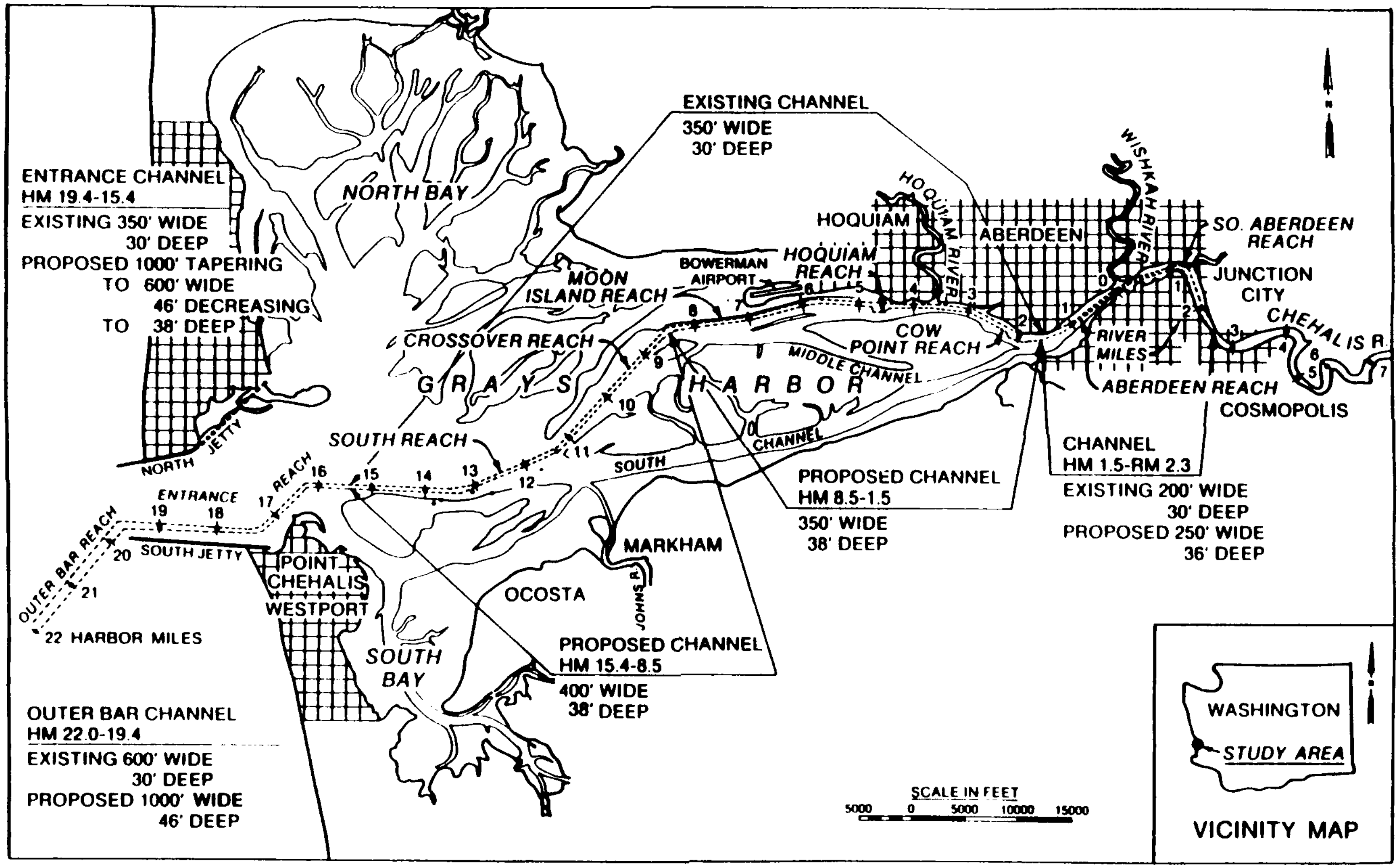


Figure 1. Location and vicinity maps

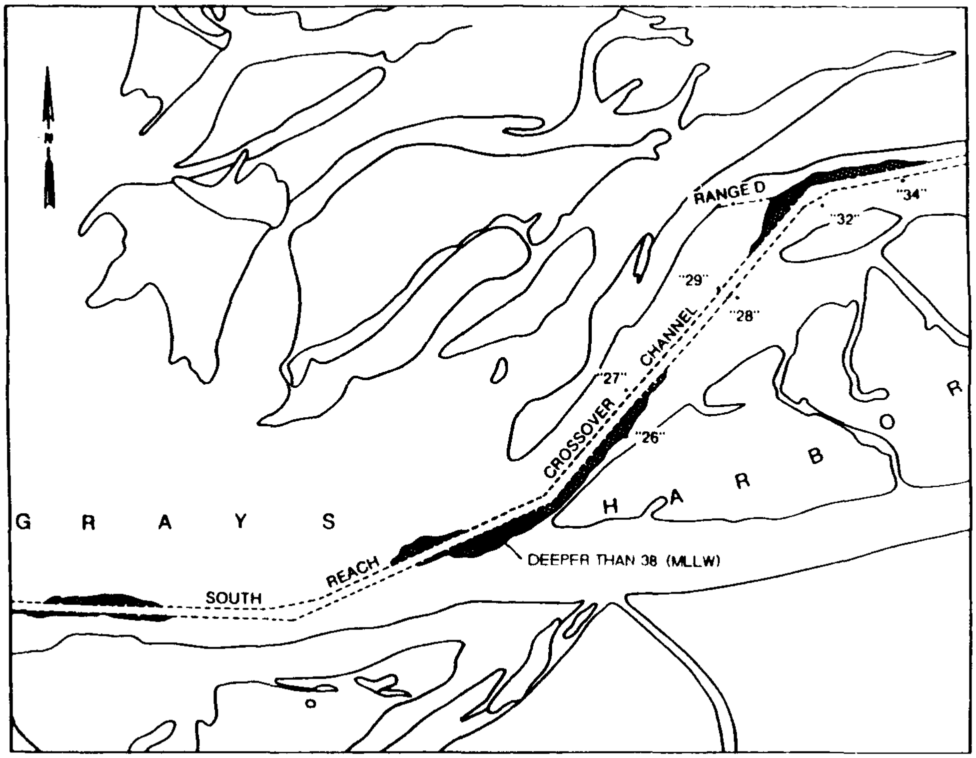


Figure 2. Outer harbor region

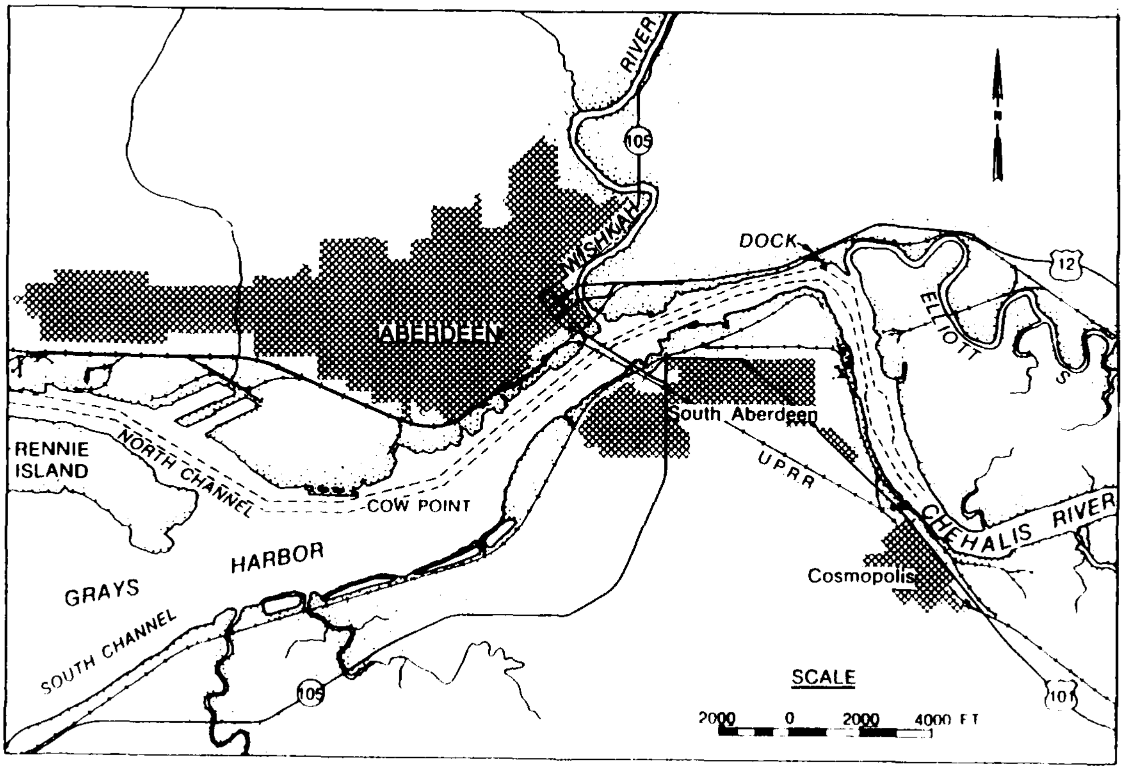


Figure 3. Inner harbor region

one-way traffic in these channels, which allows narrower channel widths. The second is that naturally deep water occurs on the outside of two of the turns, allowing the pilots more room to complete the turns (further discussion in Part III). The third turn, in South Reach, has a bend widener in place, which allows extra width for the course change. Figure 2 shows the existing conditions in the outer harbor area. The Seattle District has proposed a 400-ft-wide by 38-ft-deep, mllw, channel through South and Crossover Reaches. No widening is proposed in the Moon Island Reach, but this area was included in the scenario to provide a good starting point for the simulator tests. The specific objective for the outer harbor simulation was to test whether or not the widening is required for safe navigation of the larger ships on outbound runs. Because inbound ships are either in ballast or light-load conditions, they do not experience significant difficulty in the outer harbor and are not adversely affected by the proposed deepening. Therefore, these conditions were not tested in the present study. To accomplish the objective, a "suggested" channel (the existing 350-ft-wide channel deepened to 38 ft) was tested along with the existing and proposed channels.

Inner harbor

4. In the existing condition, the inner harbor study area includes two turning basins, a 90-deg bend, and a narrow passage through the UPRR and the US 101 bridges. Figure 3 presents the existing conditions for this region. Maneuvering through the 90-deg bend is difficult for the timber ships because of the presence of the Standard Oil Corporation dock. However, the primary navigation problem in the inner harbor is the passage through the two bridges at Aberdeen. Presently, the center swing span railroad bridge controls the clear span, which is approximately 125 ft. Passage through the bridges by the 85-ft-beam ships currently operating in the inner harbor is made more difficult because the bridges are not aligned with the channel. Seattle District has proposed modifications to the existing channel consisting of the following: (a) widening to 250 ft and deepening to 36 ft, mllw, (b) abandonment of the two existing turning basins at Aberdeen and Cosmopolis with a replacement constructed at the mouth of Elliott Slough, and (c) replacement of the existing railroad bridge with a lift bridge and modification of the existing highway bridge fendering system. The last proposal will result in a bridge clear span of approximately 185 ft. The specific objectives of the inner harbor simulation were to (a) test the adequacy of the proposed channel for safe

operation of the 625- by 100-ft timber ships, (b) determine the effect on navigation of the bridge modifications, and (c) test the design of the proposed turning basin using the tug capability of the simulator.

PART II: DATA DEVELOPMENT AND TEST CONDITIONS

5. Most of the information used for compilation of simulator input for the present study was obtained during a reconnaissance trip to Grays Harbor in August 1985. During this trip, simulator staff boarded and rode a Grays Harbor timber ship through the channel. Video and audio tape recordings were made from the bridge of the ship while transiting the harbor, from which the visual scene was generated. Discussions were held with the pilot during the operation that provided insight and practical experience into the specific navigation problems present in Grays Harbor.

6. In the following paragraphs, simulator input is discussed in general after which a more detailed description of specific Grays Harbor data is presented. In order to run a simulation study for a channel, five input data types are required:

- a. Channel geometry information is needed for the physical description. At the WES ship simulator this takes the form of a "test" file that contains initial conditions for the simulation and X and Y state plane coordinates for the channel. These coordinates represent opposite sides of the channel at each cross section, the locations of which are chosen to best describe the shape of the channel as well as to represent spatial changes in environmental conditions. This data file also contains information to define the conditions of the banks adjacent to the channel, including slope angle and overbank depth used by the simulator program to calculate bank suction forces on the test ship. Finally, the data file contains the definition of the autopilot track-line and commands to direct the autopilot during fast-time runs.
- b. Visual scene information is required including a collection of separate programs and files containing commands and coordinates that enable the graphics computer to generate the projected simulated visual scene of the local area.
- c. A list of coordinates defining the border between land and water, buoys, ranges, and key structures is required. These data are used by the computer to generate a simulated radar display on a terminal for pilot observation.
- d. A file containing a set of characteristics and hydrodynamic coefficients for the test vessel is needed. These data are used by the hydrodynamic program to calculate forces on the ship at each time-step.
- e. The simulator requires a file that defines the current magnitude and direction and water depth at eight points across the channel at each of the cross sections defined in the test file. This information can take the form of a separate file or can be included in the test file.

Simulator output consists of data files containing elapsed time; vessel position, speed, heading, engine revolutions per minute, drift angle, rate of turn, port and starboard clearance, and rudder angle; and water depth. These parameters are generated by the computer every time-step and stored on disc for future analysis. In the following paragraphs the sources of these data for the Grays Harbor simulation are described.

Channel Geometry

7. The information used for development of the channel geometry data base was obtained from postdredging survey charts made in December 1983. Seattle District also provided plotted survey cross sections at 100-ft intervals along the entire channel. The survey charts were used to obtain state plane coordinates for the definition of the simulator channel cross sections. Generally, the cross sections were located close together at bends and obstructions (such as the twin bridges) and farther apart in the straight reaches. Along each of these cross sections, eight equally spaced points were determined internally by the computer. At these points a current magnitude and direction and water depth were assigned. More information on currents is given in the section "Water Current Data."

8. Figure 4 shows views of the three tested channels of the outer harbor as implemented on the simulator. Figures 5a and 5b show the simulator existing and proposed inner harbor channel plans, respectively. All pertinent information on depth in the simulator channels is presented in paragraph 9 in a summary tabulation. The dredging survey data indicated water depths which were generally deeper than the authorized project depth for both the outer and inner harbors. This was due to either naturally deep water or advanced maintenance and overdepth dredging. However, the dredging survey also indicated localized shoaling with shallow depths along the edges of the authorized channels. Because of the wide variation of water depth in the Grays Harbor channels, the simulator channels were defined in terms of a "normal" depth based on the most frequently occurring depth on the dredge survey sheets. For the outer harbor existing channel, this nominal depth was about 34.0 ft; and for the inner harbor, it was around 30.0 ft. For the proposed and suggested channels, the nominal channel depths were 38.0 ft in the outer harbor and 36.0 ft in the inner harbor.

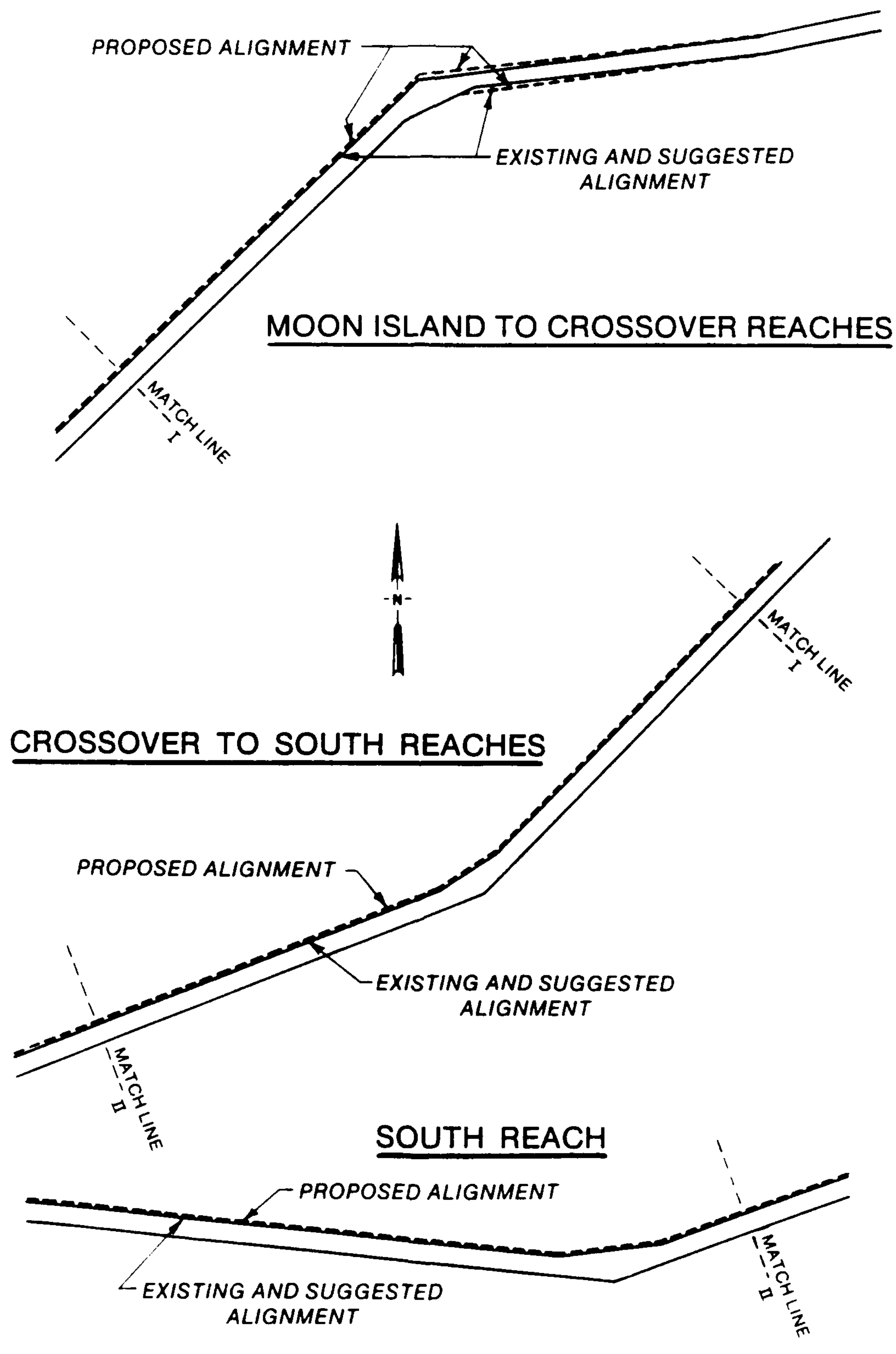
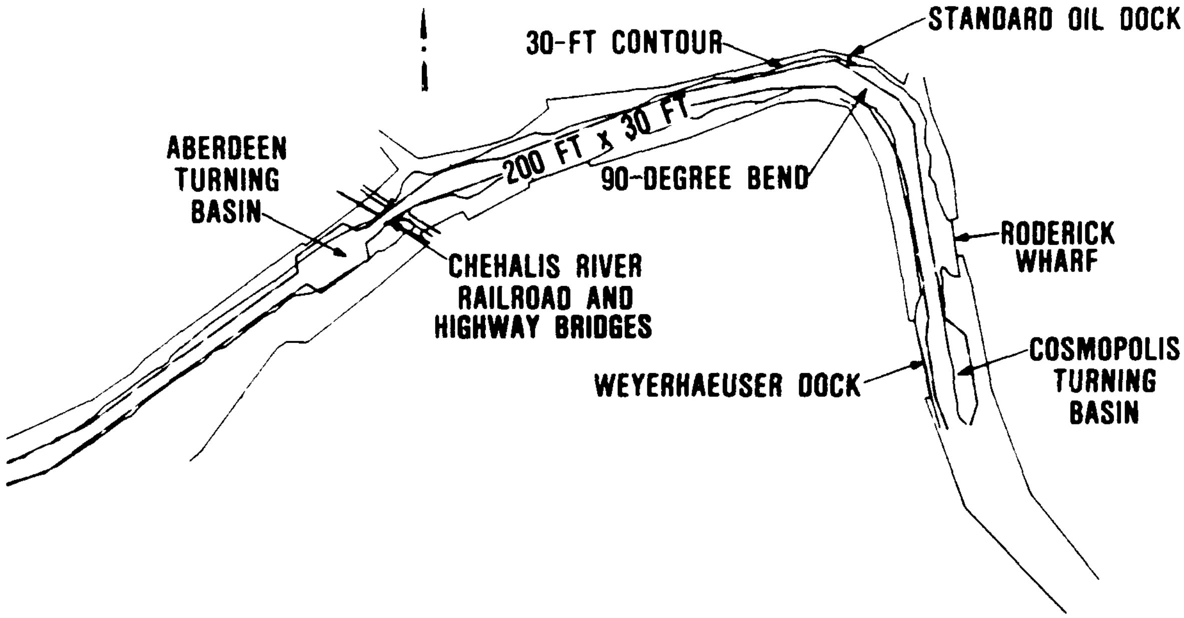
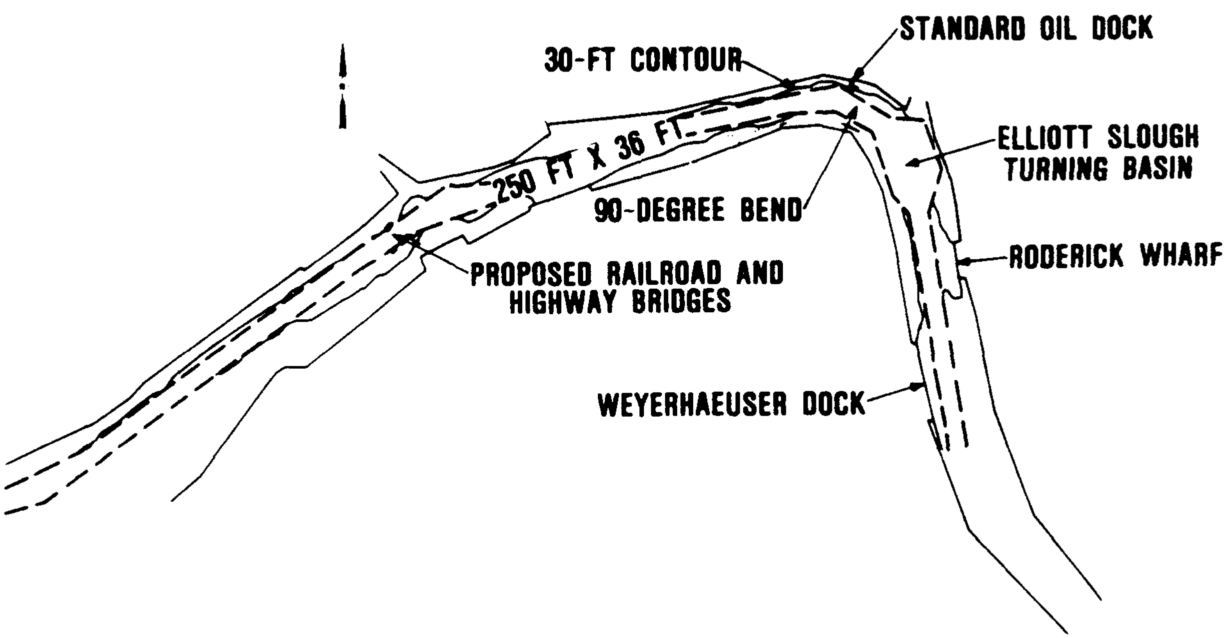


Figure 4. Channels tested in outer harbor scenario



a. Existing



b. Proposed

Figure 5. Existing and proposed inner harbor plans

9. For the present study a tidal advantage (tidal height above mllw) was added to these nominal depths to simulate the local shipping practice of operating within a tidal height time window so that heavy outbound ships do not have to be lightered. The tidal advantage used in the simulation was 4.0 and 6.0 ft for the existing outer and inner channels, respectively, and 2.5 ft for the proposed channels. The actual tested nominal channel depths are listed in the following summarization tabulation. It should again be noted that these depths represent nominal values; i.e., there were many areas in the simulator channels that were deeper. The nominal underkeel clearances shown here are based on these channel depths.

Channel	Project Authorized Depth ft	Actual Depth Range ft	Approximate Nominal Depth ft	Tested Nominal Depth with Tide, ft	Ship Draft ft	Underkeel Clearance, ft
Outer Existing	30.0	29.0-43.0	34.0	38.0	34.0	4.0
Outer Proposed	38.0	38.0-43.0	38.0	40.5	36.5	4.0
Inner Existing	30.0	0.0-68.0	30.0	36.0	34.0	2.0
Inner Proposed	36.0	36.0-68.0	36.0	38.5	36.5	2.0

10. For bank force calculations, side slopes and overbank depths were also obtained from the dredging survey sheets. Based on pilot comments and simulator testing, bank effects are not a significant factor in the navigation of the outer harbor. Bank suction becomes more significant in the inner harbor because of the restricted nature of the channel through Chehalis River. However, due to the fairly low ship speed required in the inner harbor, bank suction does not cause significant impact.

Visual Scene

11. The visual scene is a computer-generated color view of the project area showing the primary physical features required for a realistic visual simulation. These features include mountains, buildings, docks, bridges, navigational aids, and anything that is deemed necessary for determining location, orientation, or rate of motion by the pilots or simulator staff. The

scene is projected in perspective onto a large wall screen for pilot observation during testing. The graphics hardware used for the Grays Harbor project was a stand-alone computer connected with the main computer, which sends certain information required for visual scene updating. This information includes heading, rate of turn of the vessel, and position. A viewing angle is also passed to the graphics computer for the look-around feature on the simulator bridge console, which enables the pilot to look at objects to the side or rear. For the Grays Harbor project, data used for scene generation were obtained from information and material gathered mostly during the reconnaissance trip to the area in 1985. Photographs (still as well as motion), audio recordings, notes of comments made during the actual transit, and maps and charts obtained from Seattle District constituted valuable information for the development of the visual scene.

Outer harbor

12. Since only outbound transits were tested in the outer harbor scenario, the visual scene consisted mainly of water and navigational aids; only a small amount of land was visible on the western horizon. This scene was developed by WES simulator staff. Because of the few points of reference, the pilots had difficulty perceiving motion though the water. This was alleviated somewhat by generating white lines in a random fashion on the surface of the water through the channel to simulate waves. These lines remained stationary on the water, giving the pilots a feeling of relative motion and thus a more realistic condition for testing. Because of the small amount of widening, the positions of the navigational aids were not modified for the proposed channel; therefore, the visual scene for all three channels tested was the same. In addition to the geographical scene, an image of the test ship's bow had to be generated. The entire scene is drawn on the simulator relative to the bridge of the ship and the bow is always projected as the first object in the scene foreground. This part of the scene was also constructed by simulator staff and was developed from a drawing of a timber ship complete with cranes and logs. Because of the lack of any real noticeable features in the outer harbor visual scene, this scene is not shown. The next section on the inner harbor illustrates the computer-generated scene.

Inner harbor

13. The development of the visual scene for the inner harbor scenario was the most crucial task of the project. The fundamental scene was

constructed on contract by personnel at Tracor Hydronautics, Inc., Laurel, MD. The scene included the surrounding mountains, docks adjacent to the shipping channel, navigation aids, numerous old pilings, and the UPRR and US 101 bridges. The simulator staff made some modifications to the scene prior to pilot testing. The primary addition was a representation of the proposed UPRR lift bridge for the proposed channel tests. Figure 6 shows the existing and proposed bridge plans. Figure 7 shows a 535- by 85-ft timber ship passing through the existing bridges. Figure 8 shows the inner harbor visual scene on the simulator with the 535- by 85-ft timber ship approaching the two existing bridges.

Simulated Radar

14. The simulated radar data base consisted of state plane coordinates describing the border between land and water. The coordinates were obtained from the 1983 survey in conjunction with aerial photographs that aided in recognition of features. Other image data obtained from the charts included navigation markers, pilings, docks, and the bridge piers and fendering system. The simulated radar image is displayed on a terminal with three different horizontal scales available for the pilot to select. The display is simulated in the sense that the coordinates are connected with straight lines and it does not appear exactly as an actual radar with sweeping circular motion and fading images. However, all the important information is present and correctly positioned. The outer harbor scenario radar display was rather nondescript, consisting only of a number of points on the terminal representing existing navigation aids. The inner harbor area has extensive mud flats alongside the channel; in these areas the land-water boundary was programmed to be at halftide level, which approximately agreed with the timing of the tidal depth advantage in the test conditions. Figure 9 shows the radar display in the bridge area.

Test Vessels

15. The numerical model of the test ships consisted of data files of characteristics and coefficients used in the hydrodynamic program for calculating forces. These data were obtained on contract with Tracor, who

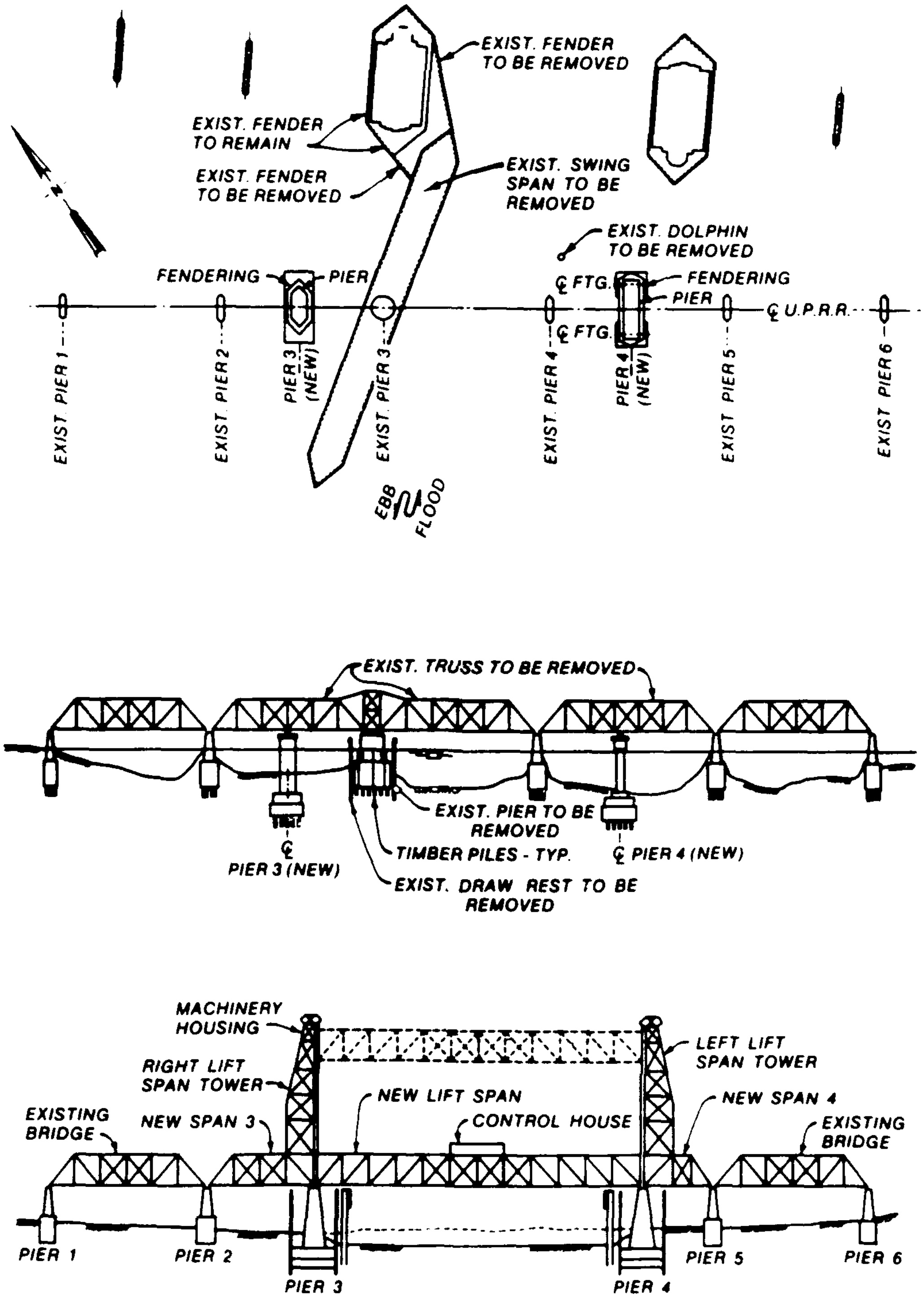


Figure 6. Existing and proposed bridge plans

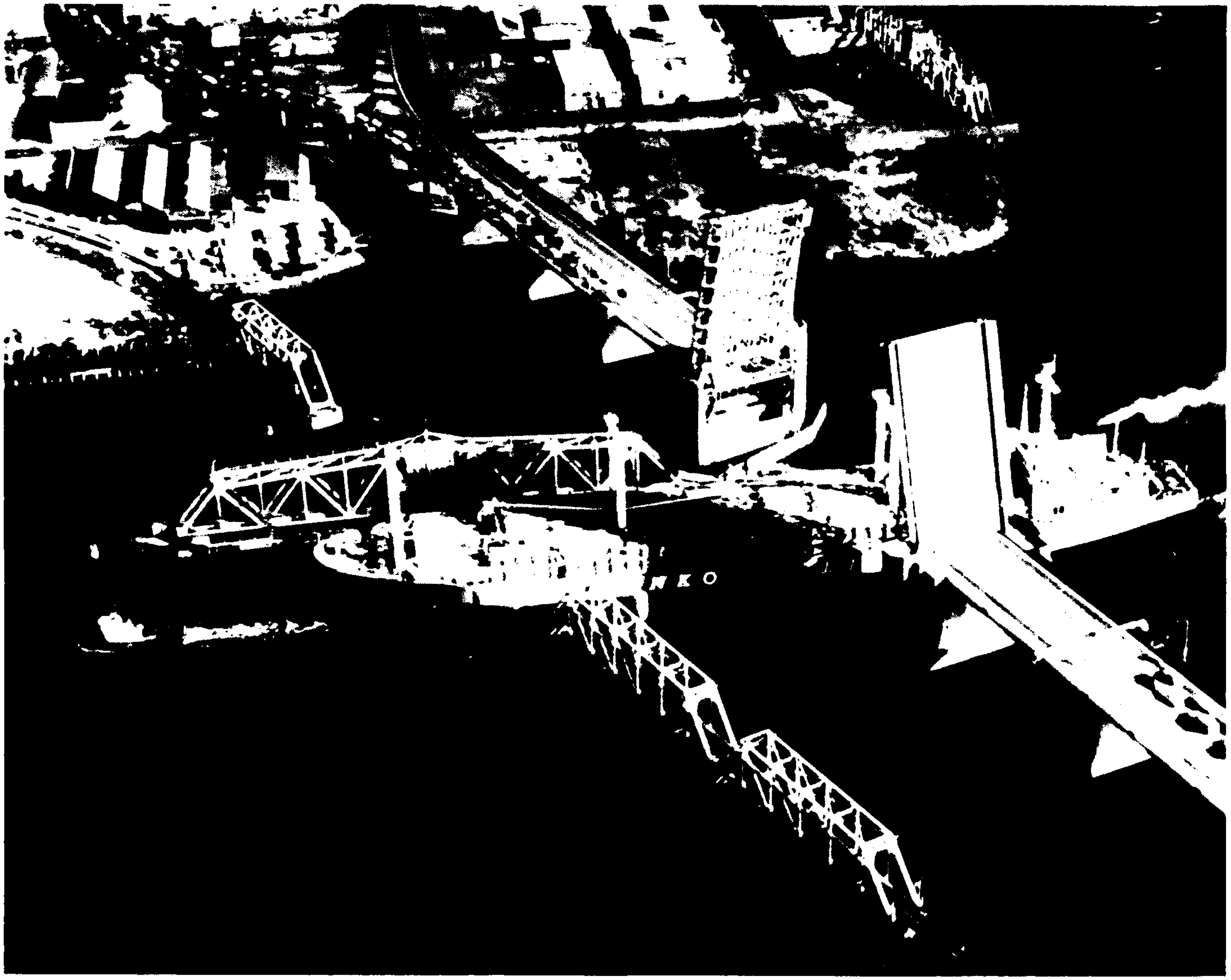


Figure 7. Timber ship passing through twin bridges

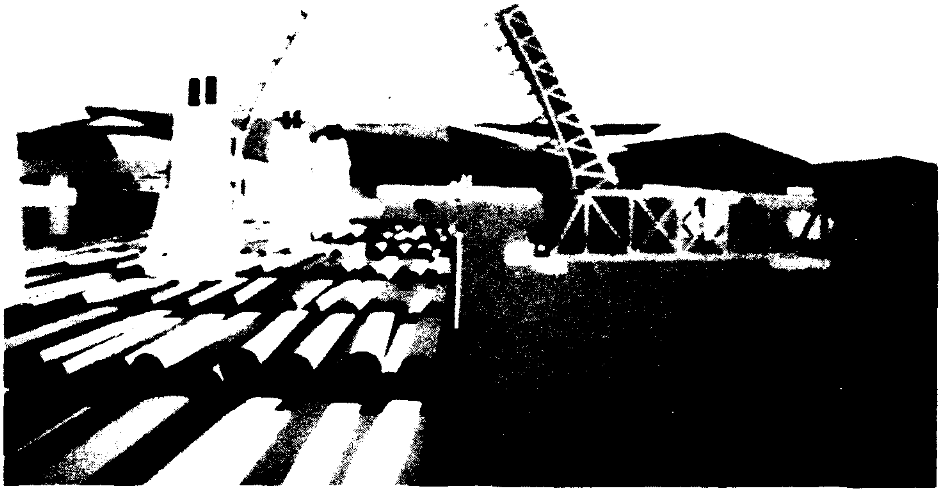


Figure 8. Inner harbor visual scene on simulator

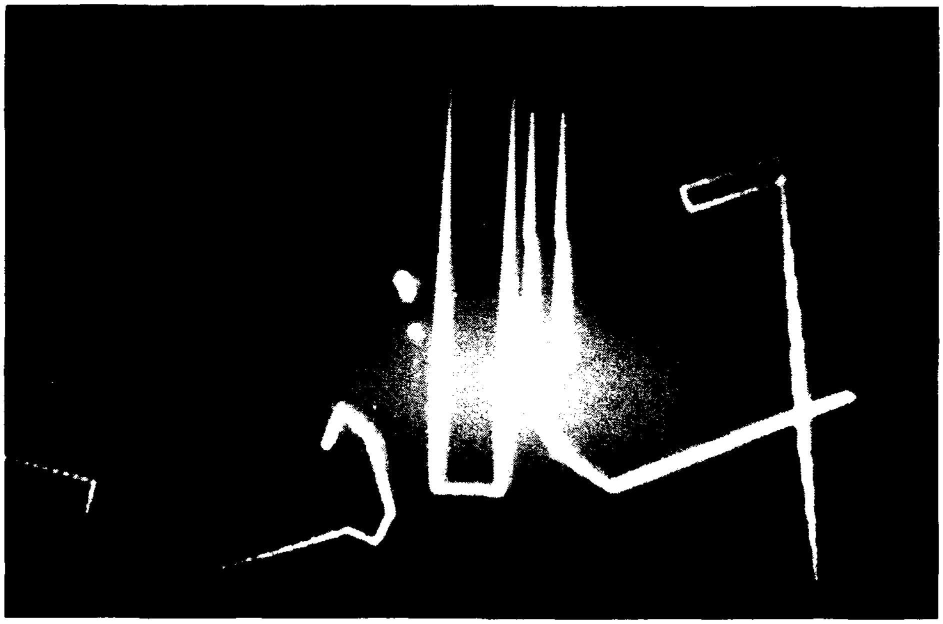


Figure 9. Simulated radar display in the twin bridge area

has conducted towing tank tests on scale models of ships similar to typical Grays Harbor timber ships. The ship models were tested using the simulator's definitive maneuver capability for the purpose of comparing the results with similar tests performed at Tracor. Six different ship configurations were developed for testing: a loaded and a ballast condition for the 535- by 80-ft, 585- by 99-ft, and 625- by 100-ft log ships. The medium-size ship was to be used only if testing proved that navigation of the largest ship in the proposed channel was not advisable.

Water Current Data

16. Current magnitudes and directions for the simulator were obtained from the physical hydraulic model of the Grays Harbor area*,** and were furnished by the Seattle District. The data consisted of measurements made along the center of the channel during flooding tide at approximately 1,500-ft intervals. This did not provide a complete representation of spatial current changes; however, it was assumed that these currents could be used. Time allowed for the study did not permit additional current modeling. In the outer harbor tests, because the ships traveled at a high rate of speed (8-10 knots), the relatively small current had less effect because of the high momentum of the vessel. The currents in this area generally were aligned with the channel and ranged from 0.75 to 1.5 knots. In the inner harbor inbound runs, no current was used in the simulation because the pilots make these transits at slack flood tide. In the outbound runs, the physical model currents were used, generally with a magnitude of around 0.5 knot. During the validation exercise, the Grays Harbor pilots operated the simulator with these currents and said they represented actual conditions adequately.

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* N. J. Brogdon. 1972 (Apr). "Grays Harbor Estuary, Washington: Verification and Base Tests; Hydraulic Model Investigation," Technical Report H-72-2, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

** N. J. Brogdon, Jr. 1976 (Apr). "Grays Harbor Estuary, Washington: 45-Ft MSL (40-Ft MLLW) Navigation Channel Improvement Studies; Hydraulic Model Investigation," Technical Report H-72-2, Report 6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Validation

17. Prior to testing, pilots from a project area visit the simulator and take part in a validation exercise. The objective of this validation is to use the local pilots' expertise and familiarity with the channel to "fine-tune" the simulation and decide upon test conditions. During the validation tests the pilots usually operate the simulator in the existing channel and give comments and feedback to the simulator staff. These comments are usually concerned with vessel response to environmental factors such as currents, wind, and shallow water and bank effects. The pilots also give constructive criticism regarding the visual scene and call attention to any missing physical object that they consider important during navigation of the waterway, for example, a church steeple they line up on or a building they use to time turns. The validation testing for the outer harbor scenario was conducted 17-18 June 1986 and the comparable tests for the inner harbor region were done on 16-18 September 1986. During this testing the pilots suggested a number of minor changes to improve the simulation. These suggestions were primarily concerned with the visual scene; however, some modifications were made to bank conditions and water depth to make the pilots feel "comfortable" with the simulation. The pilots said that the response of the simulated timber ship was very good and that the implemented currents were adequately realistic.

Test Conditions

18. Final test conditions for projects are usually decided upon during the validation exercise. For most projects the pilots who take part in the validation process do not return for actual testing; however, this was not the case for the Grays Harbor project because only four active pilots practice in the area. Three of the local pilots took part in the study testing of the outer harbor scenario, and all four were involved with testing the inner harbor region.

Outer harbor

19. In the outer harbor scenario, only outbound runs were tested. All runs were started at about HM 7 near Bowerman Airport. The three specific sets of conditions were as follows:

a. Existing channel with a 535-ft timber ship loaded to a 34.0-ft draft with a flooding tide.

b. Proposed (widened and deepened) channel with a 625-ft timber ship loaded to a 36.5-ft draft with a flooding tide.

c. Suggested (deepened but not widened) channel with a 625-ft timber ship loaded to a 36.5-ft draft with a flooding tide.

Inner harbor

20. In the inner harbor region, both inbound and outbound runs were made and four specific sets of conditions were tested:

a. Existing channel, outbound transit with a flooding tide and a 535-ft timber ship loaded to a 34.0-ft draft. Initial position of the ship was at the Weyerhaeuser dock near Cosmopolis.

b. Existing channel, inbound transit through the bridges only, at high slack tide, with a 535-ft timber ship ballasted to a 17.0-ft draft. Initial position of the ship was seaward of the bridges.

c. Proposed channel, outbound transit with a flooding tide and a 625-ft timber ship loaded to a 36.5-ft draft. Initial position was the same as in a.

d. Proposed channel, inbound transit at high slack water, with a 625-ft timber ship ballasted to a 19.0-ft draft and using two tugs for maneuvering in the proposed turning basin. Initial position was the same as in b.

In the outer harbor scenario, 18 runs were completed during the pilot testing program. Forty-five runs were completed in the inner harbor pilot testing program. Tables 1 and 2 list the runs completed in each area. Table 2 includes eight tests (23-30) with a 6.0-ft tidal advantage for the proposed 36-ft-deep channel. Although this was a test error, it was not considered significant since all these tests were for ballasted inbound log carriers at 19-ft draft in slack water. The depth-to-draft ratio changed from 2.0 to 2.2, and differences in shallow-water effects on ship maneuvering are insignificant at these values.

PART III: TEST RESULTS

Outer Region

21. Composite ship track plots from all conditions tested during the outer harbor simulation are shown in Figures 10-14. It is important in interpreting the test results for the outer harbor scenario to understand the hydrography along the navigation channel. Figure 2 shows the appropriate region of the Grays Harbor navigation chart* with the areas deeper than the presently authorized 30-ft depth outside the navigation channel highlighted by crosshatching. Because of the importance of the region's hydrography, all the ship track figures include the 30-ft-mllw contour digitized from the Seattle District Grays Harbor survey charts reflecting the conditions during the period January 1983 to January 1984. In areas where the 30-ft contour was beyond the survey data, an estimated contour is drawn. As mentioned in Part I, both the bend between Moon Island and Crossover Channels (first bend) and the bend between Crossover and South Channels (second bend) have substantial areas of naturally deep water on the outside that are habitually used by the pilots. Figure 10 shows two ship tracks from the validation tests with two pilots using their normal strategy of swinging wide through the turns beyond the channel limits. Figure 11 shows the same pilots maneuvering through the channel after being asked to "stay in the channel as best you can." The natural tendency of the pilots to swing wide is still evident, but only a slight drift beyond the channel limits occurred.

22. Pilot runs from the regular testing program for the existing channel conditions are presented in Figure 12. This composite plot is composed of the five runs completed during the regular testing program conducted with a loaded timber ship 535 ft long and 80 ft wide. The two existing channel runs shown in Figure 11 are not shown in Figure 12 but were included in the analysis and clearance calculations in Table 3. These runs indicate the same strategy discussed previously, i.e., swing wide to the outside of the bends. During one test the pilot went well out of the channel in the first bend, but returned before the shallow area on the west channel edge. Except on the

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* From National Oceanic and Atmospheric Administration Chart 18502, November 1984.

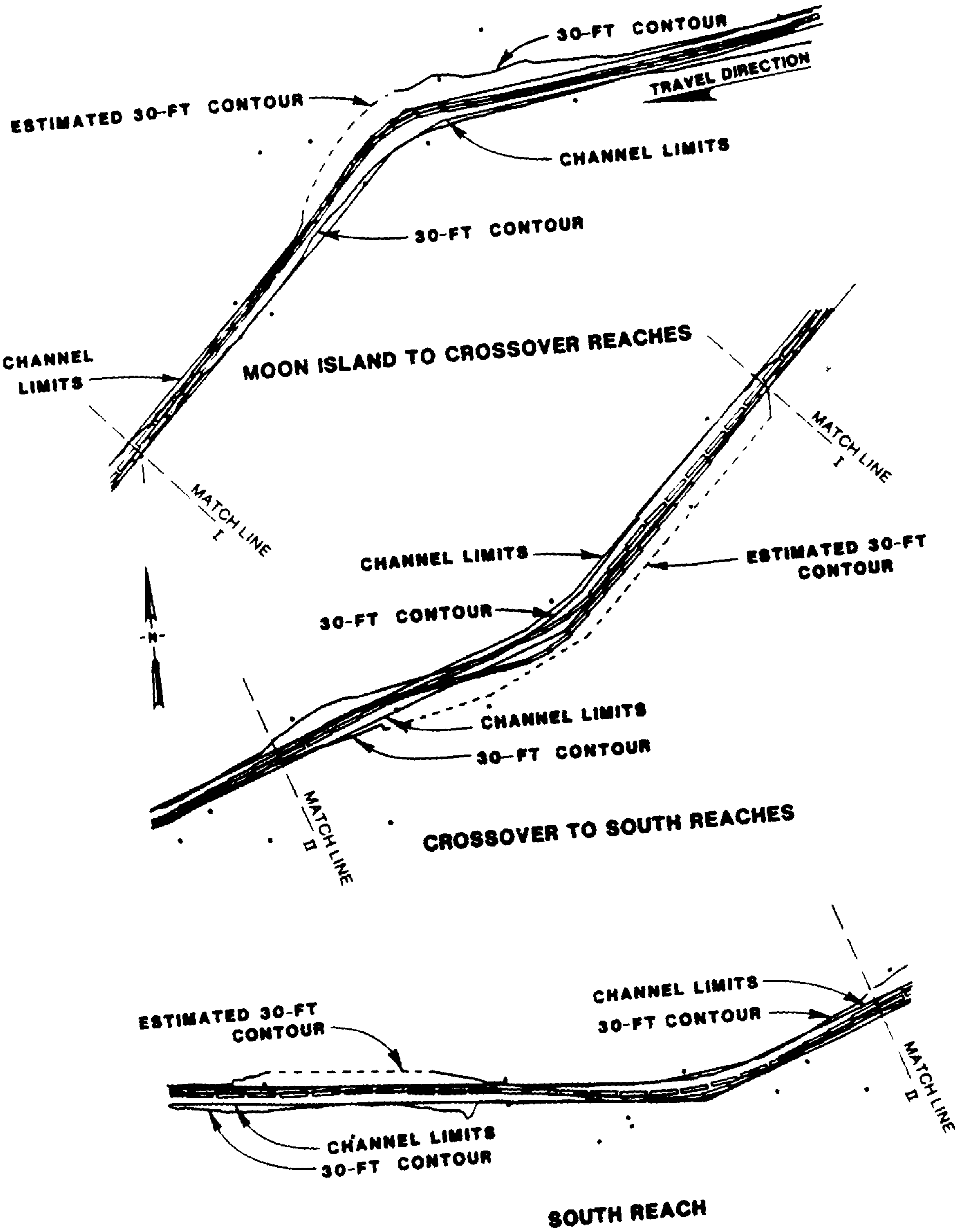

Figure 10. Ship track plots from validation tests, outer region, normal strategy

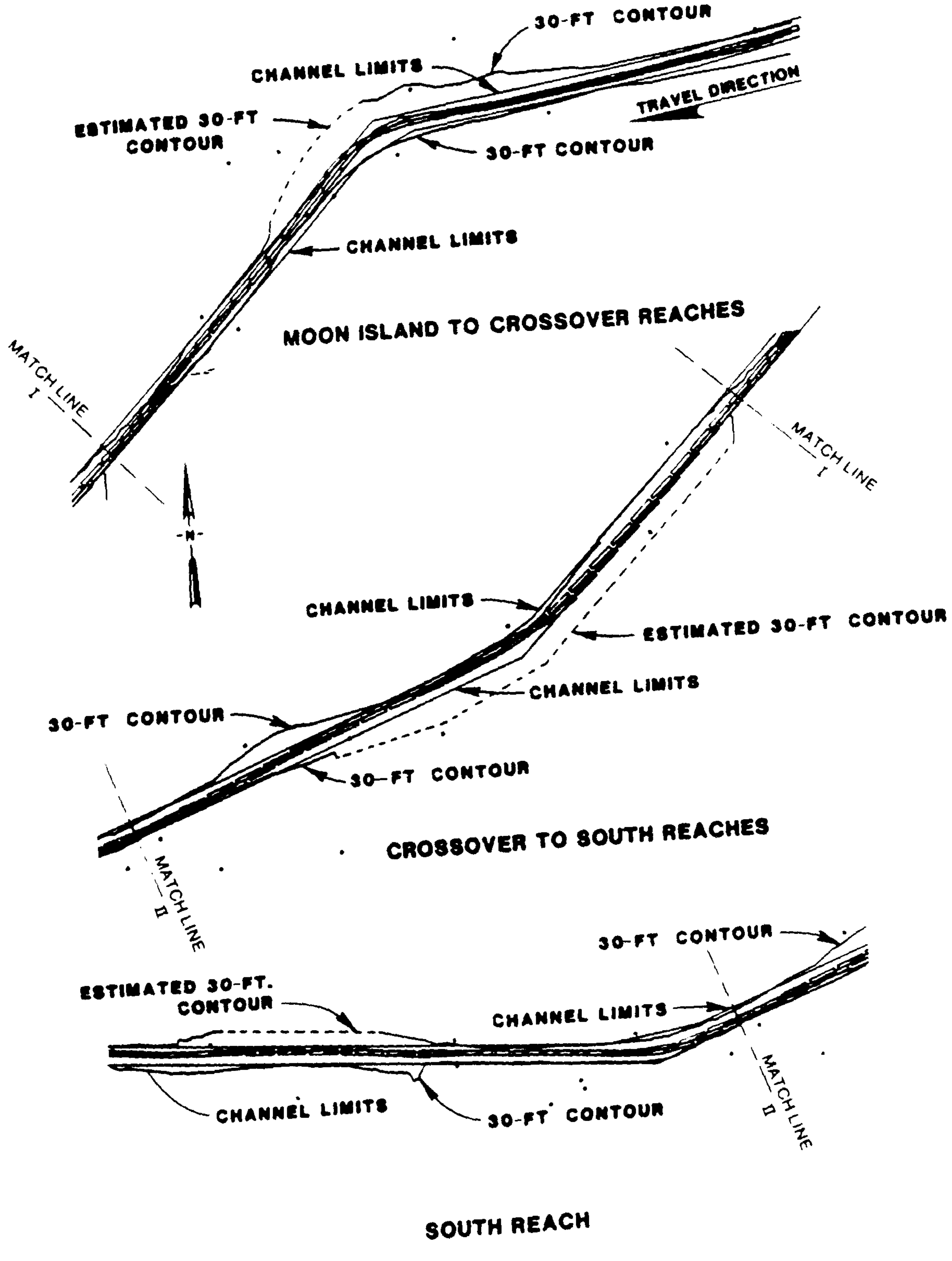

Figure 11. Ship track plots from validation tests, outer region, alternative strategy

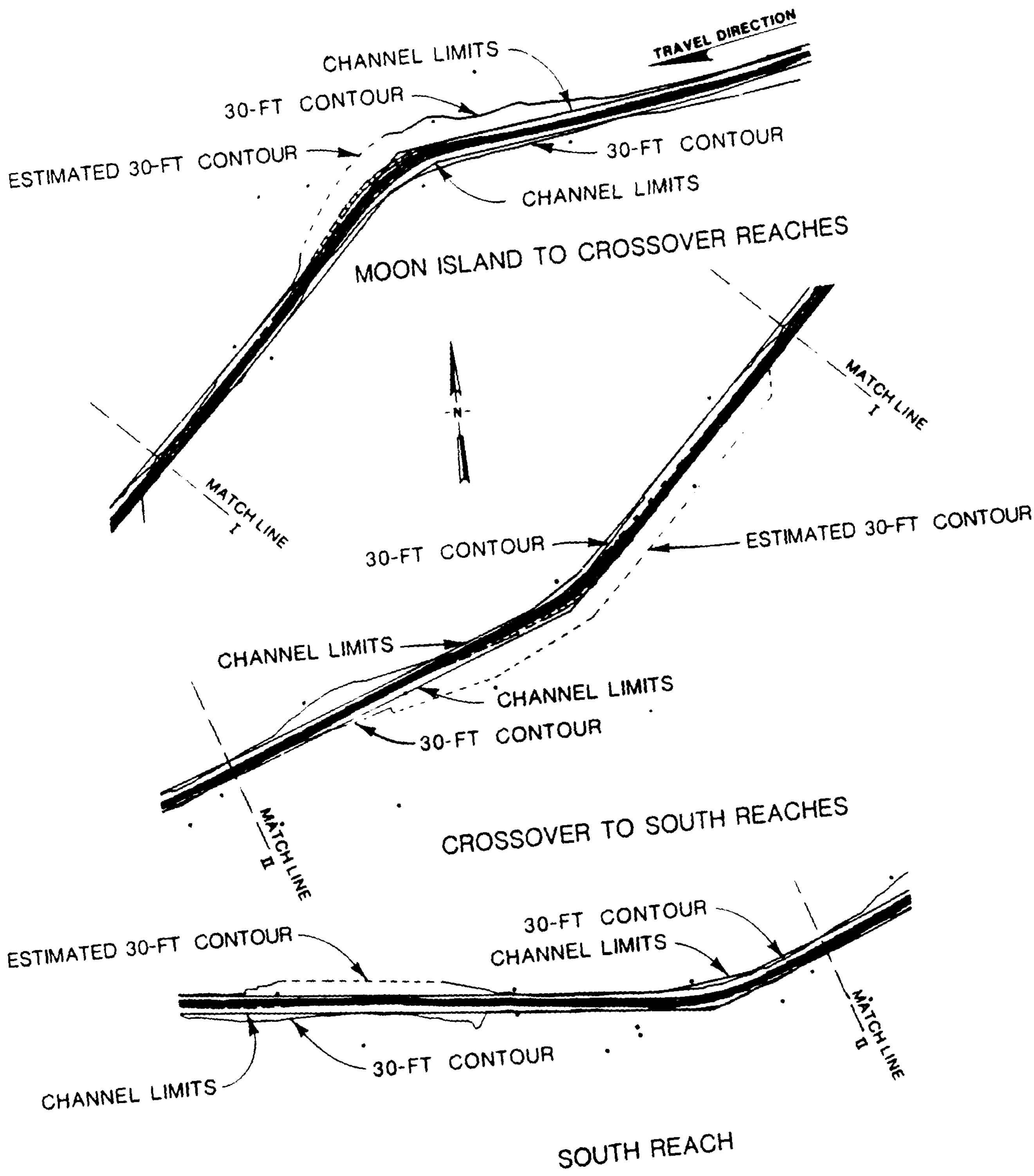

Figure 12. Pilot runs from regular testing program for existing channel, outer region

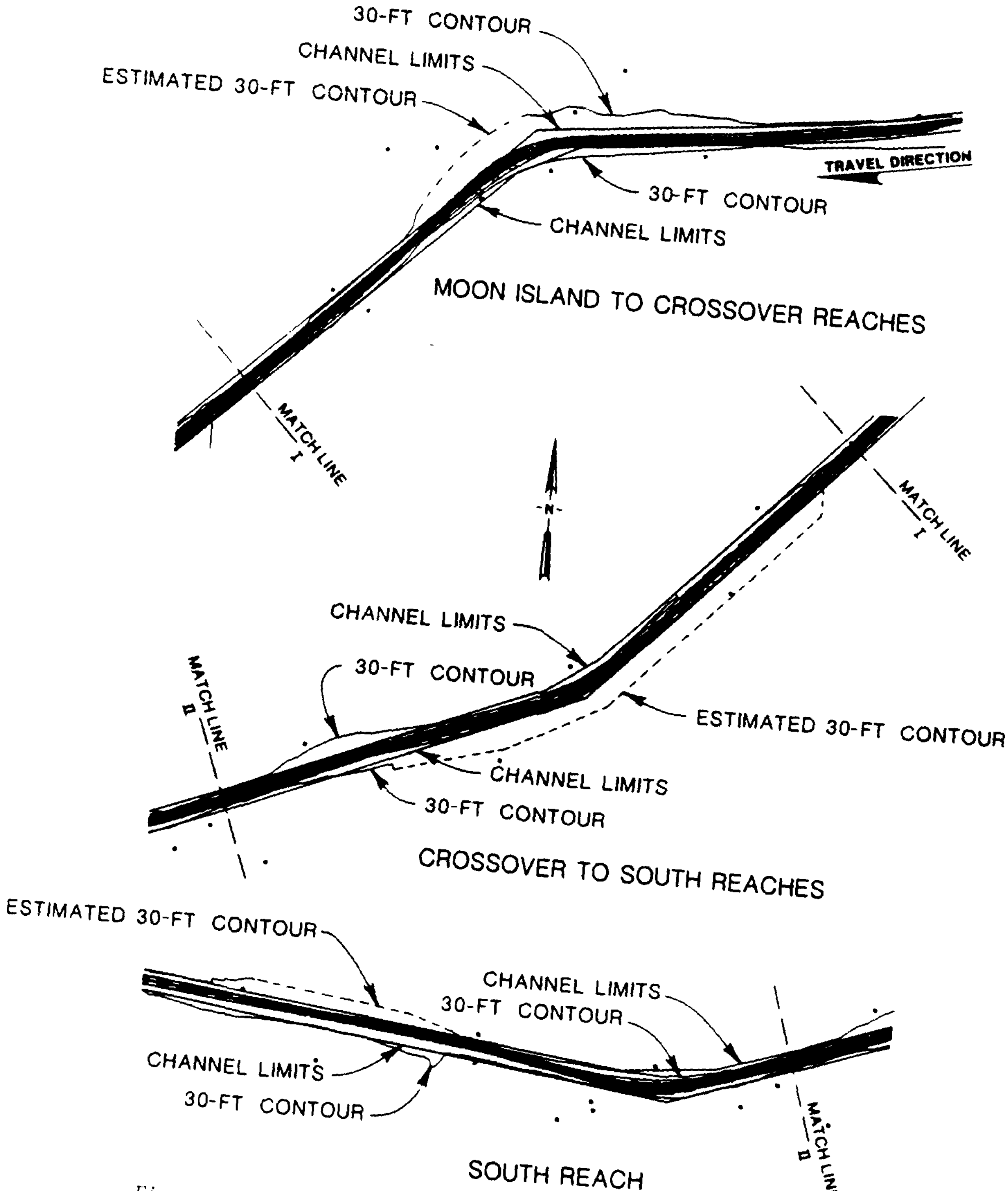

Figure 13. Composite track plots for proposed channel, outer region

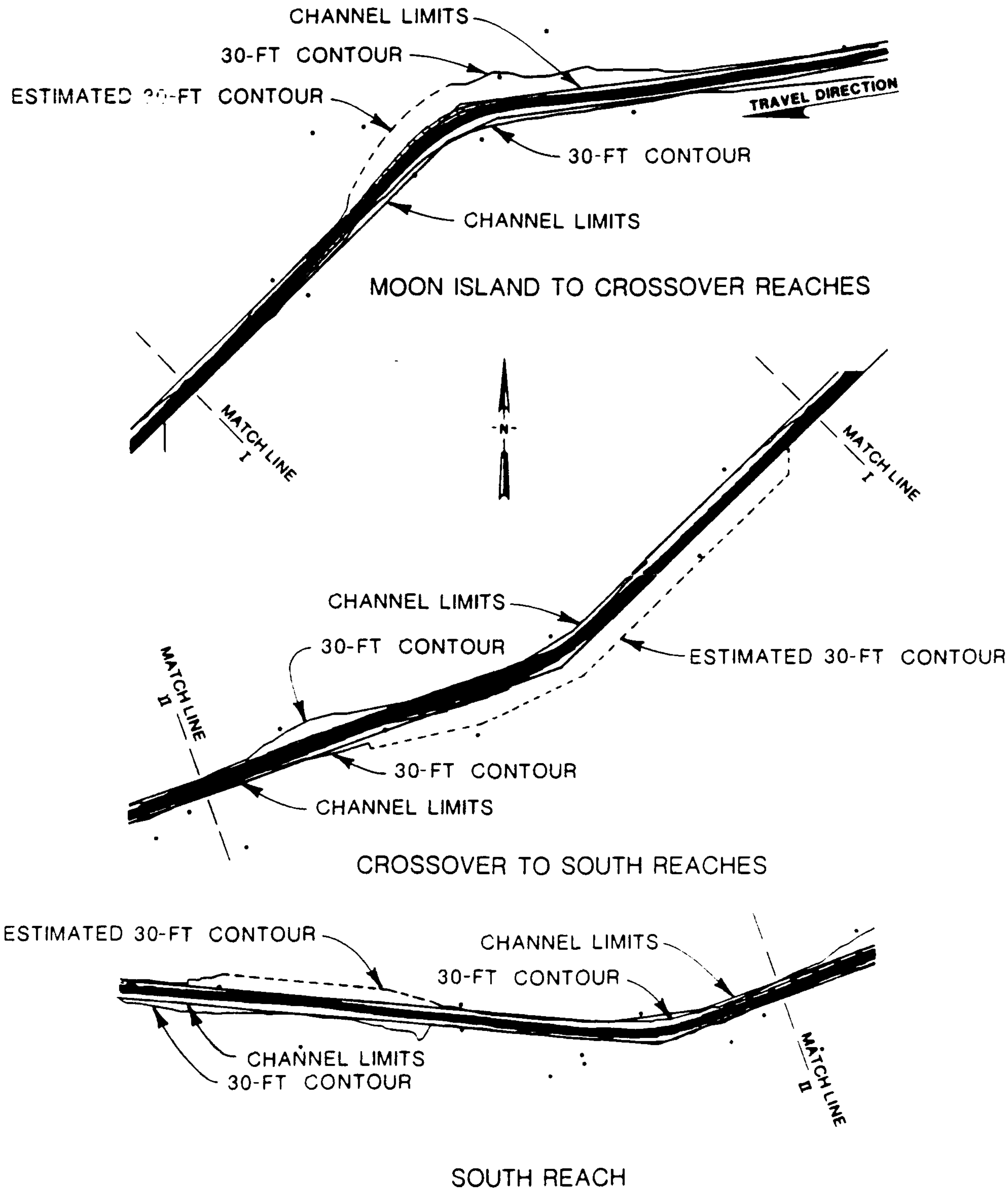

Figure 14. Composite track plots for suggested channel, outer region

dramatic effect on the mean minimum starboard clearance with a value of +17. In the second region essentially the same minimum port clearance was recorded for all three tested channels. This holds true for the mean port clearance in this region also. These results indicate that the 25-ft widening on the outside of the bend would not be adequate to allow the ships to stay within the authorized channel.

25. The simulator tests indicate very similar results for all three channel conditions: existing, proposed, and suggested. This is especially the case in the straight channel reaches. Some of the tests in the suggested channel indicate some difficulty in the first and second bends, with a tendency to drift out of the existing channel at the outside edge. Since the suggested channel width (350 ft) is less than the proposed width (400 ft), it clearly would be more economical to dredge the suggested channel. The test results from the proposed channel condition indicate that a 25-ft widening on both sides of the channel is not adequate for the maneuver around the first two bends. It is recommended that the channel retain the existing 350-ft width except for a 100-ft widening on the north side of the seaward end of the first bend and an equal widening on the south side of the seaward end of the second bend. Referring to Table 3, clearances were recalculated for the recommended channel alignment and show marked improvement for the mean minimum starboard clearance in the first region and mean minimum port clearance for the second region. Figure 15 presents two sketches of these proposed channel wideners. Figure 16 shows all the recorded ship track plots (existing, proposed, and suggested) from the test program superimposed on the recommended channel alignment. Only two ship tracks can be seen straying beyond the widener limits in the first bend and none in the second bend. These wideners would be constructed in areas of naturally deep water, and the cost of the additional dredging should be relatively small.

Inner Region

26. Figures 17-23 show the results of the pilot testing program for the inner harbor region. These figures include delineations for four different areas along the length of the inner harbor scenario. This subdivision of the pilot runs was carried out to differentiate between clearances along different reaches of the channel. The clearances calculated in these areas, in

seaward side of the second bend, the pilots stayed in water deeper than 30 ft mllw. Figures 13 and 14 show composite track plots for the proposed and suggested channels, respectively. The proposed channel plot is composed of six pilot runs and the corresponding number for the suggested channel is seven. Both conditions were tested using a loaded timber ship 625 ft long and 100 ft wide. Generally, the pilots used the same strategy for these conditions as they used in the existing condition; however, there were fewer excursions beyond the channel edge in the proposed channel because of the 400-ft width. Generally, the ship tracks are grouped closer in the existing and suggested channels, although this is not the case seaward of the second bend.

23. Another method of observing pilot strategy and comparing navigability of different channels is to look at averaged clearances. Table 3 shows mean and mean minimum clearances for the outer region pilot runs. These data were obtained from simulator output data files recorded during testing. The trends discussed in the preceding paragraphs are apparent in these data. Included in the table are values for the recommended channel, which will be discussed later. Both the mean and minimum port clearances for the proposed channel in the first region are much less than the corresponding values in the other channels; this would suggest that the pilots were attempting to take advantage of the increased width by moving over and not preparing for such a wide turn. In any event, this occurrence is not considered significant because no groundings were recorded and the maneuver around the first bend was not affected. Table 3 in conjunction with the track plots indicates that the pilots had little difficulty in the straight reaches in the three tested channels. The results also indicate no problems with the third bend in South Reach with good clearances for both sides in all channels. Therefore, the suggested channel should be adequate in these areas, and only on the outside of the first two bends does the channel need modification.

24. The most significant values in Table 3 are the mean minimum starboard clearance in the first region and the mean minimum port clearance in the second region. A negative mean minimum starboard clearance was recorded for the first region in the existing and suggested channels, indicating the pilot's wide swing around the first bend. The extreme value of -61 in the suggested channel indicates difficulty in keepirg the larger ship within the existing alignment. Although in the proposed channel two pilots strayed beyond the channel limits in the first bend (Figure 13), the widening had a

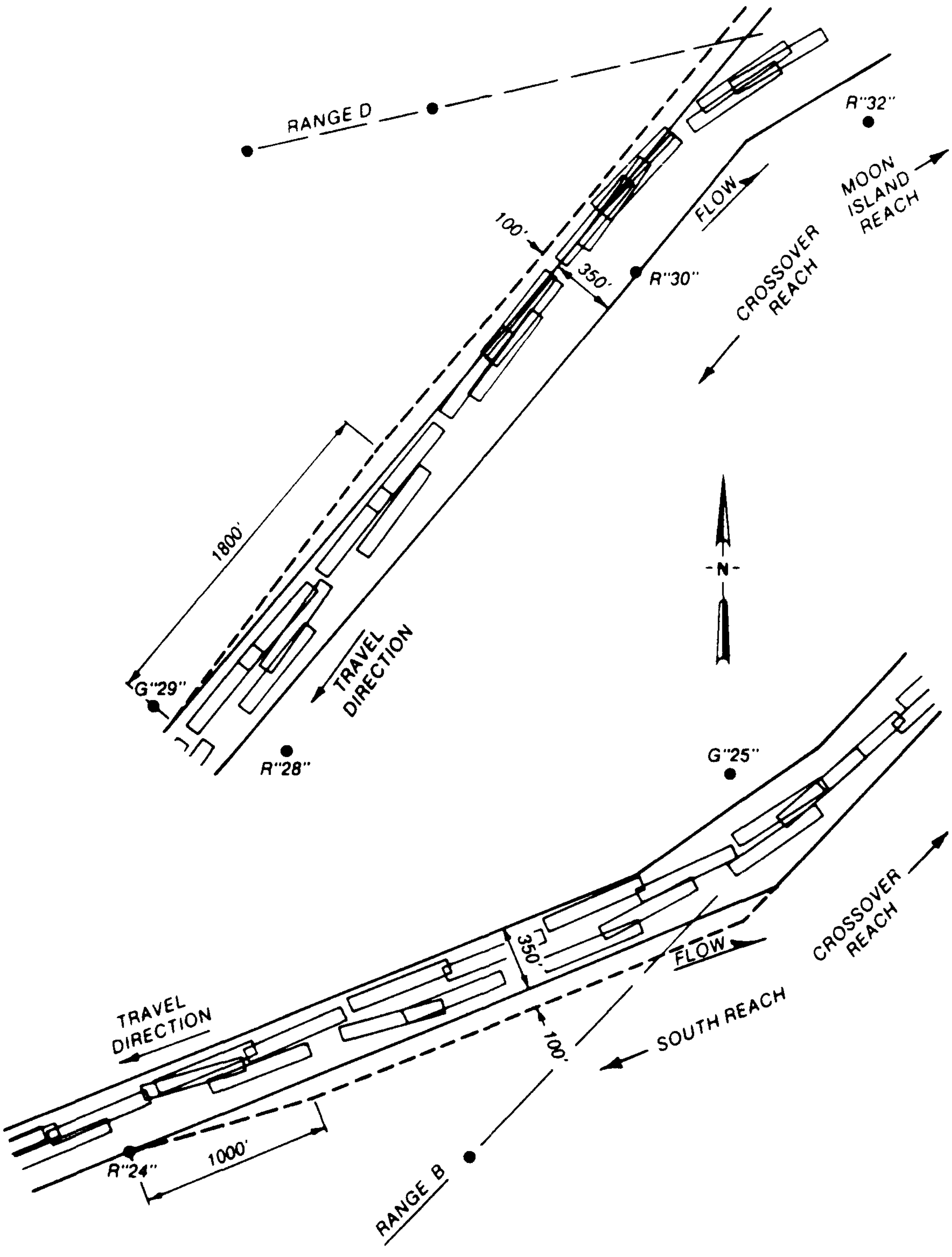

Figure 15. Recommended channel wideners for outer harbor region

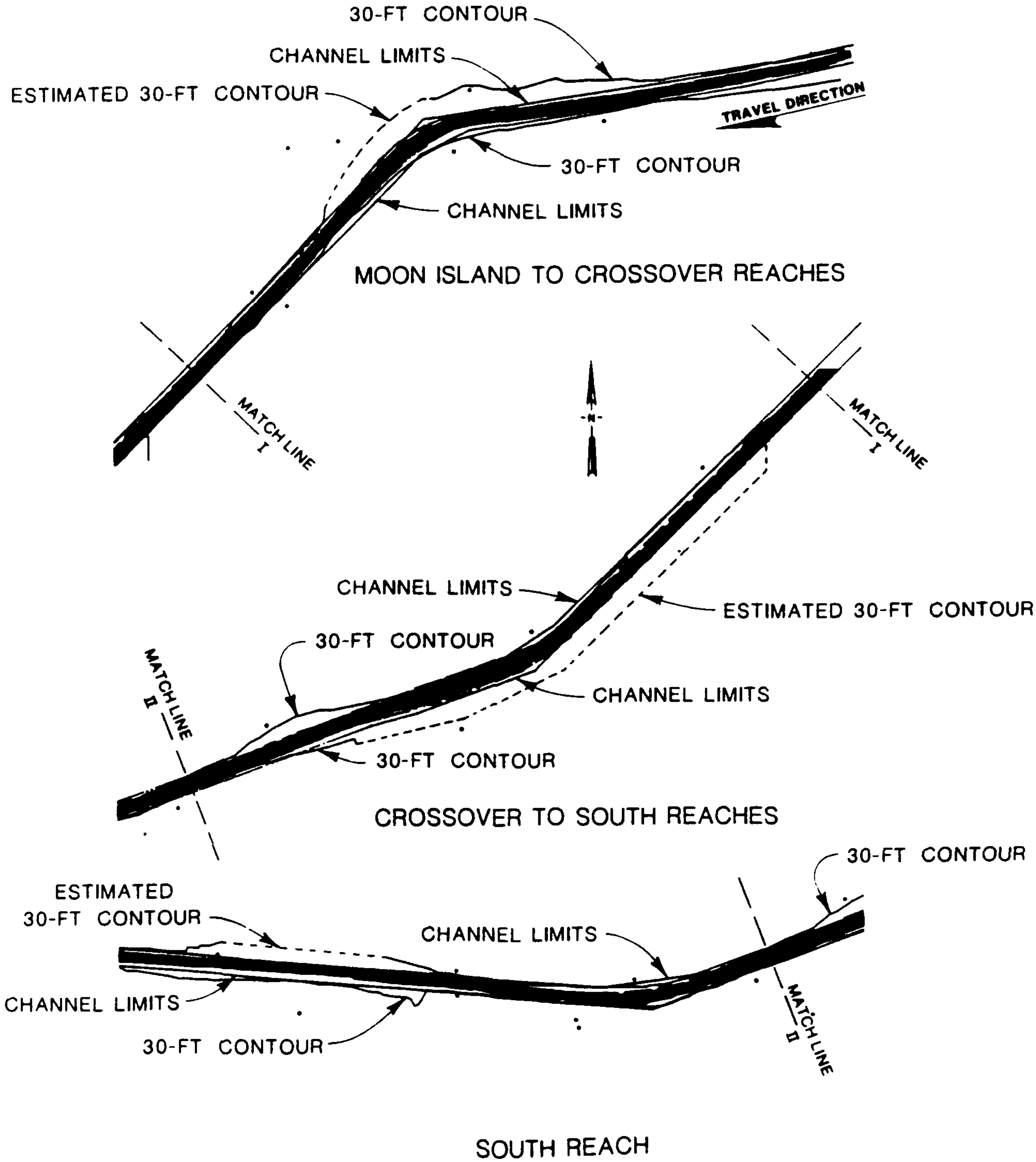

Figure 16. Recorded ship track plots superimposed on recommended channel alignment

conjunction with track-line plots, are useful in determining problem areas. Comparison of clearances in the different test channels for the inner harbor region is discussed later in this section.

Outbound tests

27. Figure 17 shows composite pilot runs for the existing channel outbound test condition with the smallest loaded ship. The upper part of Figure 17 shows a consistent maneuvering pattern with all the pilots crossing immediately from their initial position at the Weyerhaeuser Corporation dock to the east side of the channel in front of Roderick Wharf. According to the pilots this maneuver is common practice in preparation for the sharp 90-deg bend. The maneuver is so routine that all of the pilots, with the exception of one, drifted well out of the Federally maintained channel. Most of the pilots stayed in water deeper than the 30-ft contour during this maneuver because navigable depths are privately maintained in this area. Generally, the passage around the 90-deg bend was handled without incident as a result of this wide turn. Although most pilots steered clear of the Standard Oil dock, a couple came fairly close. If the dock was not there, the pilots would probably not swing quite as far to the eastern side of the channel before the bend, which they do to keep their stern clear. After emerging from the bend, the pilots all drifted beyond the south edge of the channel in area B (the channel line cannot be seen at this point because the ship tracks cover it) before crossing to the north side in area C to prepare for the approach to the bridges. Some pilots tended to go beyond the channel limits here also. Since the Chehalis River is naturally deep in these last two areas, no groundings occurred; however, the vessels are outside the existing authorized channel. The outbound passage through the bridges with the loaded log ships proved to be very difficult, as at least two pilots actually rammed the railroad bridge swing span draw rest (inset in Figure 17). While there has not been any serious accident at the real bridges, in actual practice this passage is considered to be very difficult by the pilots.

28. Figure 18 shows the composite ship track plots for the proposed channel outbound runs. These tests were conducted with the largest timber ship with the same initial conditions as for Figure 17. As can be seen, the pilots performed the same maneuver as in the existing channel, i.e. crossing immediately to the east side of the channel. In this condition, however, the channel was wider and the excursions beyond the edge were smaller. The

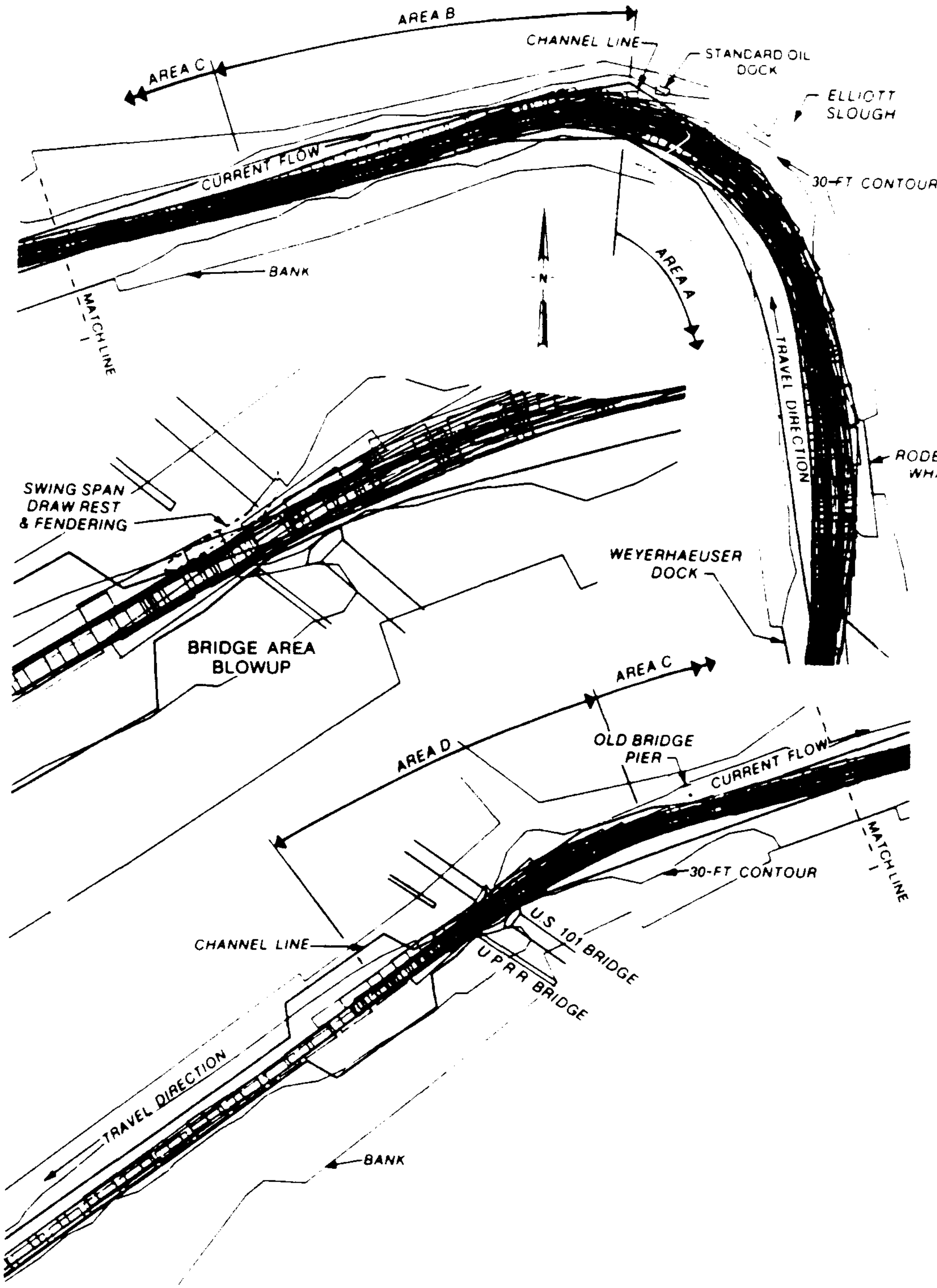

Figure 17. Composite outbound pilot runs, existing channel, inner region, loaded 535-ft ship

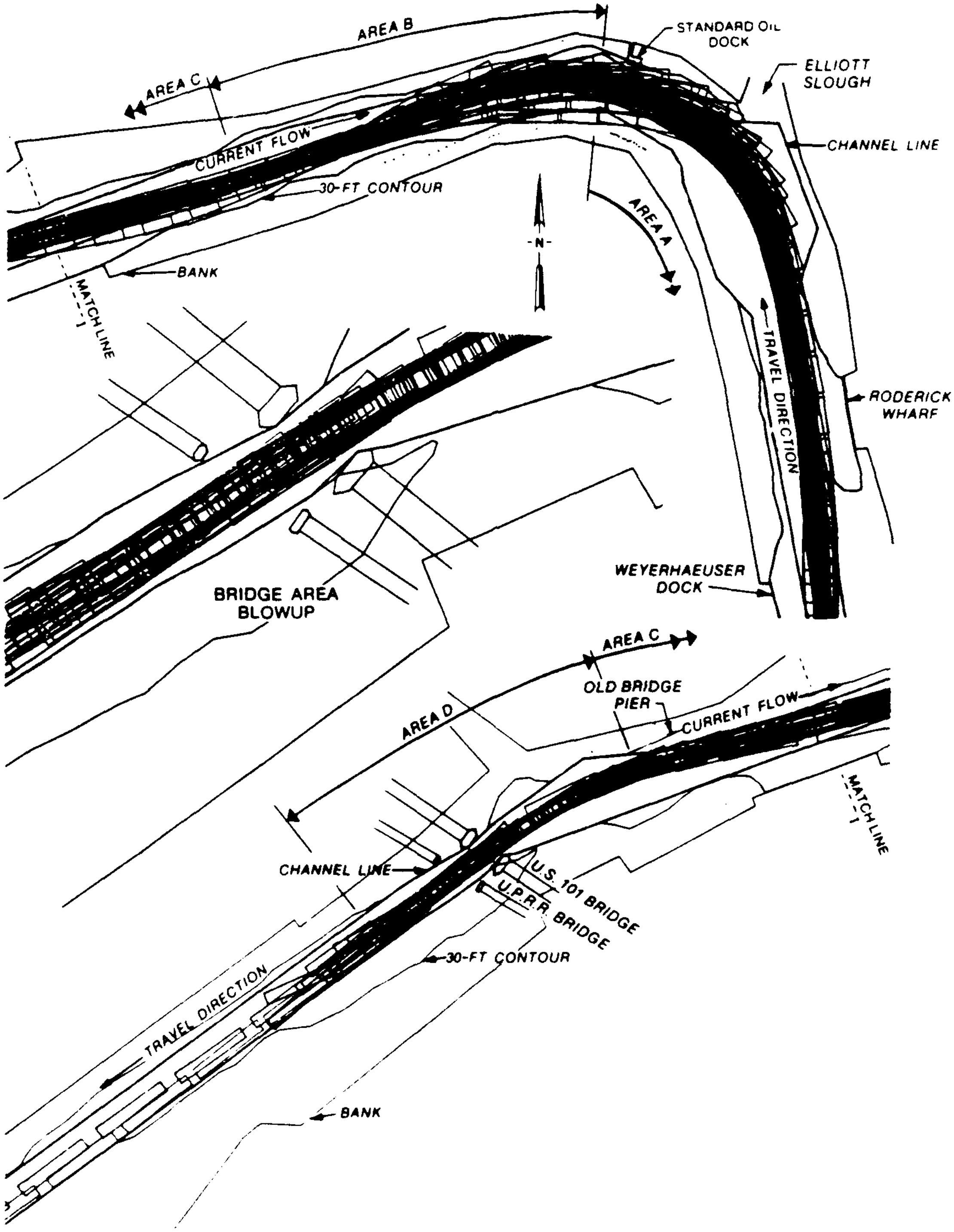

Figure 18. Composite outbound pilot runs, proposed channel, inner region, loaded 625-ft ship

passage around the 90-deg bend shows a large amount of variability with one pilot hitting the Standard Oil dock and another coming very close. Two other ship tracks show that the pilots turned too sharply across the inside of the curve and probably ran aground since it is shallow in this area (the simulation does not end with a grounding). This wide variance in ship tracks around the bend is considered to be due to pilot unfamiliarity with handling the larger ship in this area. It is evident that the proximity of the Standard Oil dock on the outside curve of the bend will pose a hazard with the larger ships. After the maneuver around the bend, all the pilots crossed to the south side of the channel. Many of the pilots drifted beyond the southern limits of the widened channel here but stayed within the deep water (30-ft contour). Following the same strategy as used in the existing channel, the pilots crossed back to the north side in area C to get in position to pass through the bridges. At this point, a few of the pilots again crossed the channel line in the vicinity of the old bridge pier. The passage through the bridges in the proposed channel with the modified railroad bridge in place was much easier, as shown in the enlarged view in Figure 18.

29. As in the outer region, average clearances were calculated for different reaches of the inner harbor channel. Table 4 presents mean and mean minimum clearances for outbound runs in the four regions shown on the track plots. As before, some of the differences seen in the table can be correlated to trends and strategies discussed in preceding paragraphs. Others require explanation and, because of the exact nature of area subdivision, are not necessarily meaningful. In these areas of uncertainty the track-line plots became useful in determining what points along the channel received the most weight in the calculation of the numerical clearances. Because of the way in which the pilot runs were subdivided, some of the clearances contributing to the mean values in one area actually occurred in an adjacent area. This is because the statistics were allocated to the subareas based on the position of the center of the ship; some of the time the vessel might have been straddling two areas with the center in one area and the bow or stern (where the clearance is computed) in the adjacent area. The clearances for the recommended channel in Table 4 will be discussed in a later section of the report.

30. The port clearances in area A reflect the repositioning of the turning basin from Cosmopolis to Elliott Slough; i.e., the mean clearance did not change but the mean minimum clearance dropped significantly in the

proposed channel. This decrease is not considered significant because part of the river which the pilots use in this area is maintained privately, and the simulation tests considered only the authorized Federal channel for clearance calculations. An additional reason for the decrease in port clearance in area A is that two pilots cut too sharply across the inside curve of the 90-deg bend. The starboard clearances in area A show a significant increase in the proposed channel because of the widening and the addition of the new turning basin on the east side of the channel. The mean minimum starboard clearance here shows the average pilot still drifted beyond the channel edge along Roderick Wharf a distance of approximately one ship beam. However, in the existing channel the minimum clearance shows a corresponding value of over two ship beams.

31. In area B, the mean port clearance exhibited an increase in the proposed channel because the channel was to be widened on the south side through this area (the same occurrence can be seen in area C). The mean minimum port clearance in area B shows essentially no change with the widening. The corresponding clearance in area C shows a small increase. From Figure 18 it can be seen that the point where the minimum port clearance occurs through this reach straddles areas B and C (with the exception of the inside curve of the 90-deg bend in area B). Despite these small improvements in the proposed channel, it is apparent that the south side of the channel in this area needs to be moved even further south to accommodate standard pilot practice.

32. The starboard clearances in area B for the proposed channels show small decreases from those of the existing channels. This occurrence might be expected because the proposed channel was not widened on this side in this area and the ship itself was 20 ft wider than in the existing condition. It is apparent that some difficulty was experienced by the pilots in keeping the stern of the larger ship clear in this area, especially in the vicinity of the Standard Oil dock.

33. The starboard clearances in area C show that the pilots crossed the channel line on the north side just above the bridges. With the larger ship (Figure 18) the mean minimum clearance here exhibited a significant drop, suggesting that the channel should be wider in this area. Through the bridges in area D the proposed channel allowed increased clearances for all but the minimum starboard clearance, which was affected by the straddling of the ship across areas C and D.

Inbound tests

34. Figure 19 shows test results for inbound runs in the existing channel for the inner region. The testing focus for these runs was the passage through the two bridges. The tests were begun well downstream of the bridges with the smallest ship in a ballast condition. The passage through the bridges was generally conducted at around 5 knots, and the pilots experienced little trouble because of the straight approach. However, the sharp bend above the bridges caused the ship to slide beyond the north side of the maintained channel. This is the main feature of Figure 19 that indicates that widening is needed in this general area.

35. Figure 20 shows the composite track plots for the inbound proposed channel tests. These tests were conducted with the largest ship in a ballast condition with two tugs used for the turning maneuver in the proposed turning basin near Elliott Slough. The upper part of the figure shows that the passage through the bridges with the proposed bridge modification in place went smoothly with no accidents and much more room than shown in Figure 19. The pilots passed through the bridges at about the same speed as in the existing condition tests. Because of the larger mass of the ship, this speed resulted in higher momentum coming into the sharp bend above the bridges. As a result, the slide to the north side of the channel was worse than in the existing channel simulations with at least one pilot hitting the old bridge pier above the bridge. In addition, the plot shows that because the bridges are aligned with the channel, widening is not required on the south side just upstream of the highway bridge as the pilots did not use this area on either outbound (Figure 18) or inbound transits (Figure 20). Through area B the pilots had difficulty keeping their stern clear of the 30-ft contour on the north side; however, this is not considered significant because the inbound ships had a draft of only 19.0 ft.

36. The lower part of Figure 20 shows the results of the turning basin tests. Usually, the pilots had two tugs tie alongside in the straight reach through areas C and B and then had them back down to slow the vessel around the eastern end of area B. The plot shows some variation in turning strategy; however, the differences seen can be attributed to pilot unfamiliarity with the new turning basin design. The first few pilots tested turned the ship where they normally turn in the existing channel close to Elliott Slough rather than in the simulated turning basin. This problem was alleviated

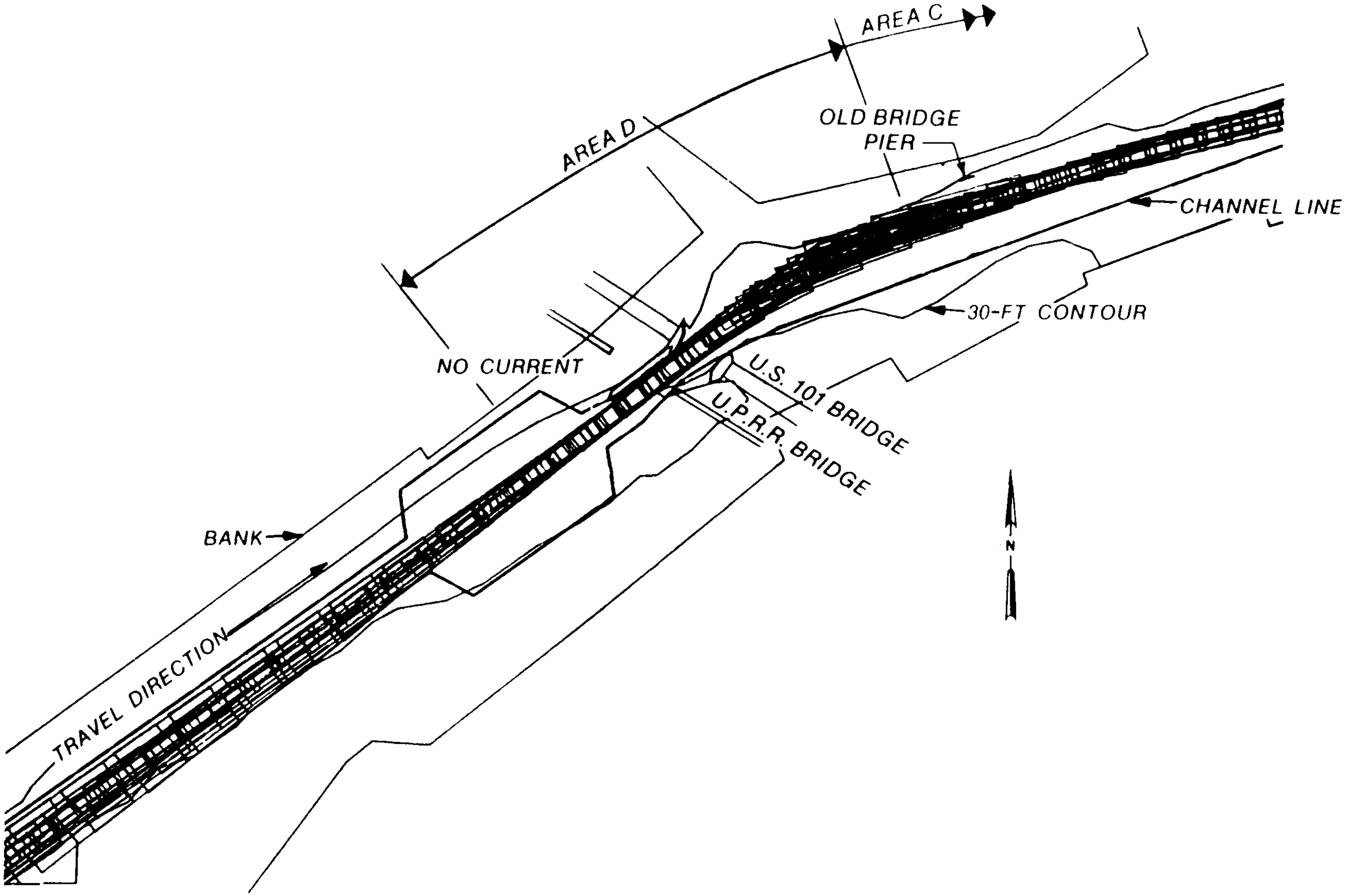

Figure 19. Composite inbound pilot runs, existing channel, inner region

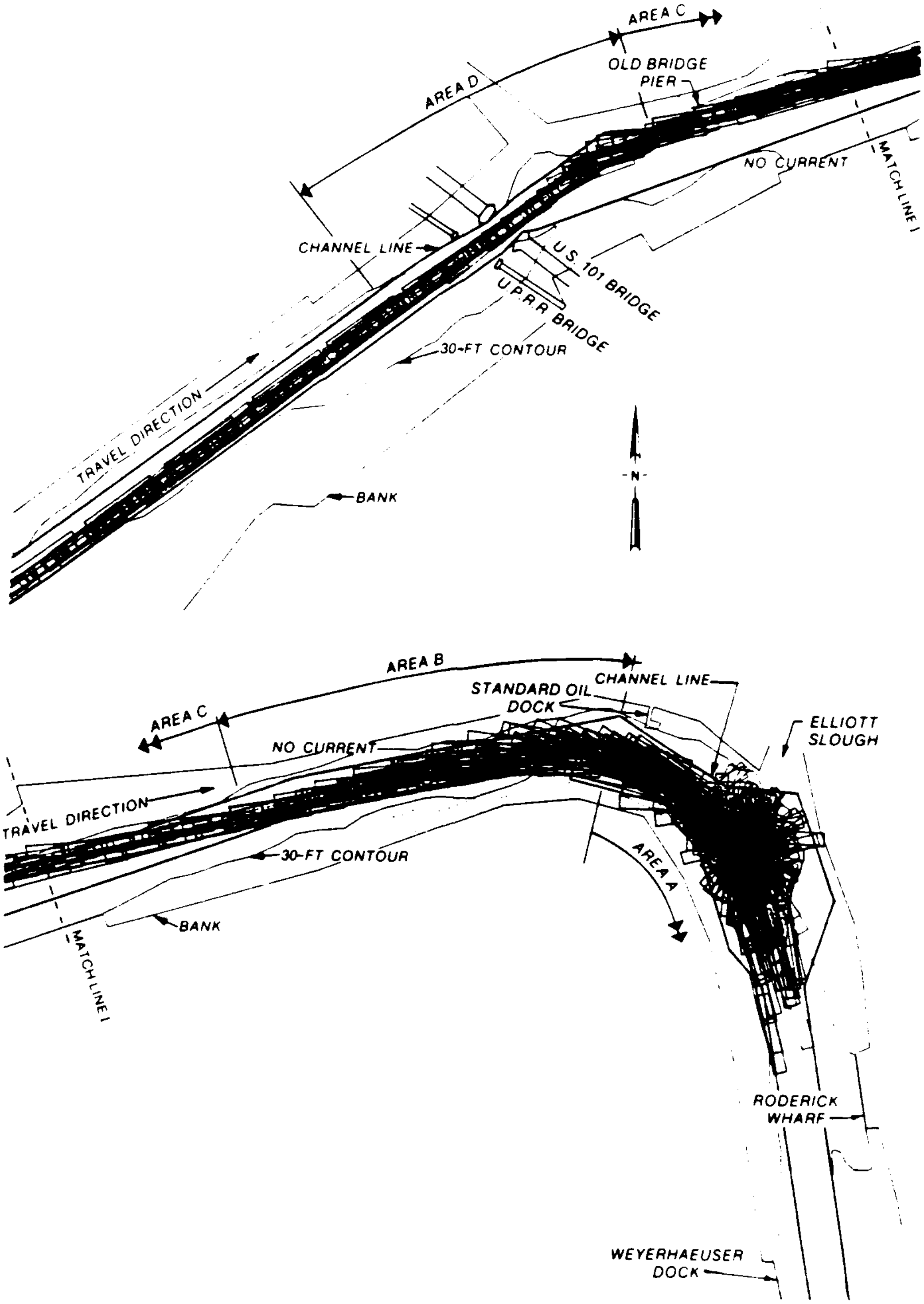

Figure 20. Composite inbound pilot runs, proposed channel, inner region

somewhat by placing markers in the visual scene and radar display of the simulation at the two back corners on the east side of the basin. Nonetheless, the composite center of the turning maneuver is shown by the plot to be away from the center of the new turning basin. The performance in the prototype proposed turning basin should improve as the pilots become accustomed to the new location and develop a workable strategy for conducting the turning operation. The most important point to be derived from this plot is that the turning diameter envelope for the largest ship is about the same as the proposed turning basin width of 750 ft.

37. Table 5 presents the mean clearances and mean minimum clearances generated from the inbound run simulations. Only data for area D are available for comparison of the existing channel with the proposed channel. In paragraphs 38 and 39, clearances for the recommended and proposed channels for all areas are compared. For area D the proposed channel allowed increased clearances in all except the mean minimum port clearance. The decrease in the proposed channel in this instance is a result of the slide out of the channel on the north side above the bridges as discussed earlier. This is further evidence that extra widening is needed in this area.

38. The test results indicate that it is feasible to navigate the inner harbor region upstream of the bridges with the proposed channel and railroad bridge modifications using the largest ship tested. The bridge modifications significantly improve the safety of ship navigation, both inbound and outbound. The proposed turning basin size and location should be adequate. However, a few problem areas remain which the simulations suggest would be alleviated by modifications to the proposed channel alignment. In addition, the tests show that part of the proposal would require unnecessary channel widening. Figure 21 shows the recommended modifications to the proposed channel alignment. The 350-ft channel width between the bridges and the 90-deg bend is recommended because the combination of outbound and inbound runs requires more room than the proposed 250 ft. The channel widener in the 90-deg bend and removal of the Standard Oil dock should make the bend safer to negotiate. Since this dock has been abandoned and is becoming dilapidated, removal cost should be minimal. On the south side of the channel just above the bridges, the channel does not need to be dredged as far to the east as the proposed channel definition. Removal of the old bridge pier above the bridges and relocation of the channel marker in the same area would eliminate a

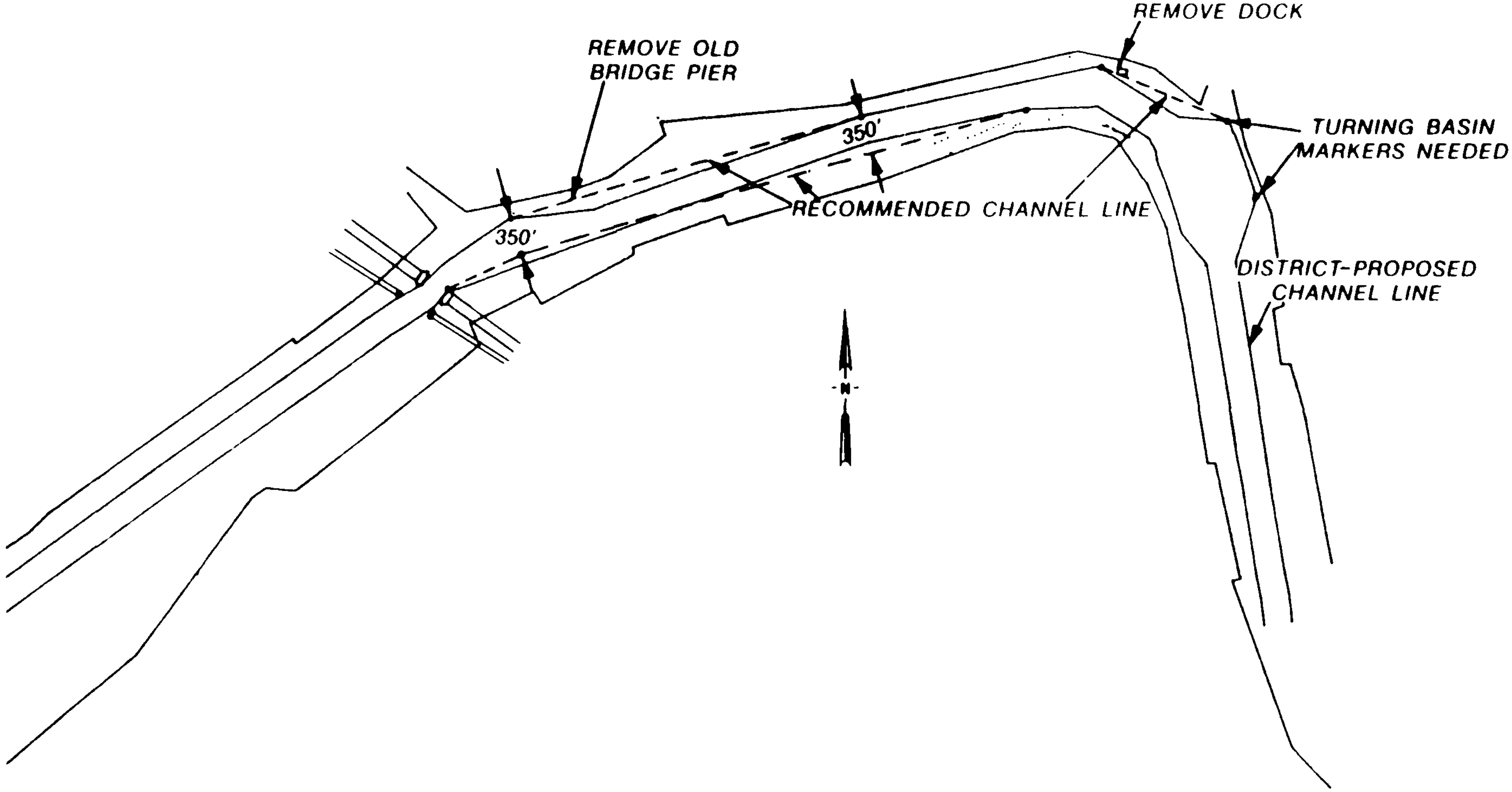

Figure 21. Recommended channel alignment

possible hazard. In the turning basin, the placement of corner markers would help the pilots locate the turning basin limit.

39. As a final indication of the validity of the recommendations, the proposed channel pilot runs were superimposed on the recommended channel to check the location of the track plots with respect to the changes and recheck clearances to the channel edge. Figures 22 and 23 show the outbound and inbound pilot runs, respectively, with the recommended channel. A few of the stray pilot runs still cross the channel line in the particular areas discussed earlier; however, it would not be realistic to base the proposed recommendations on these extreme examples. The clearance calculations in Tables 4 and 5 for the recommended channel indicate increased or unchanged clearances in most instances. The main exception is in area D where it was recommended that the channel not be widened on the south side. The recommended channel allowed for much greater mean and mean minimum clearances on the north side above the bridges; however, on inbound runs in this area the mean minimum clearance is still shown as being negative in this area. This would not affect safety if the old bridge pier was removed since the inbound ships are loaded only to 19 ft and can safely venture outside the deepened channel to a depth of about 21-22 ft.

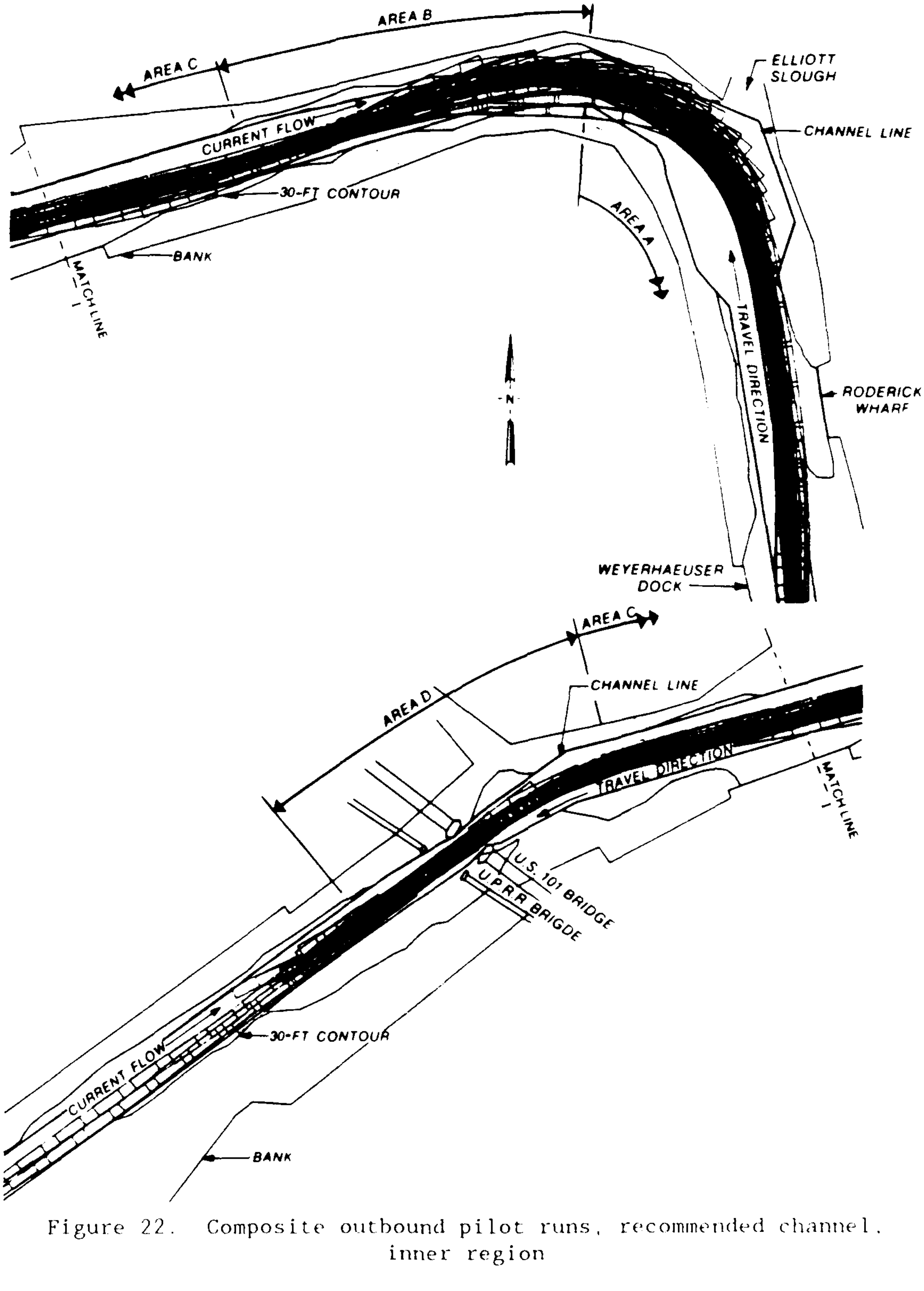

Figure 22. Composite outbound pilot runs, recommended channel, inner region

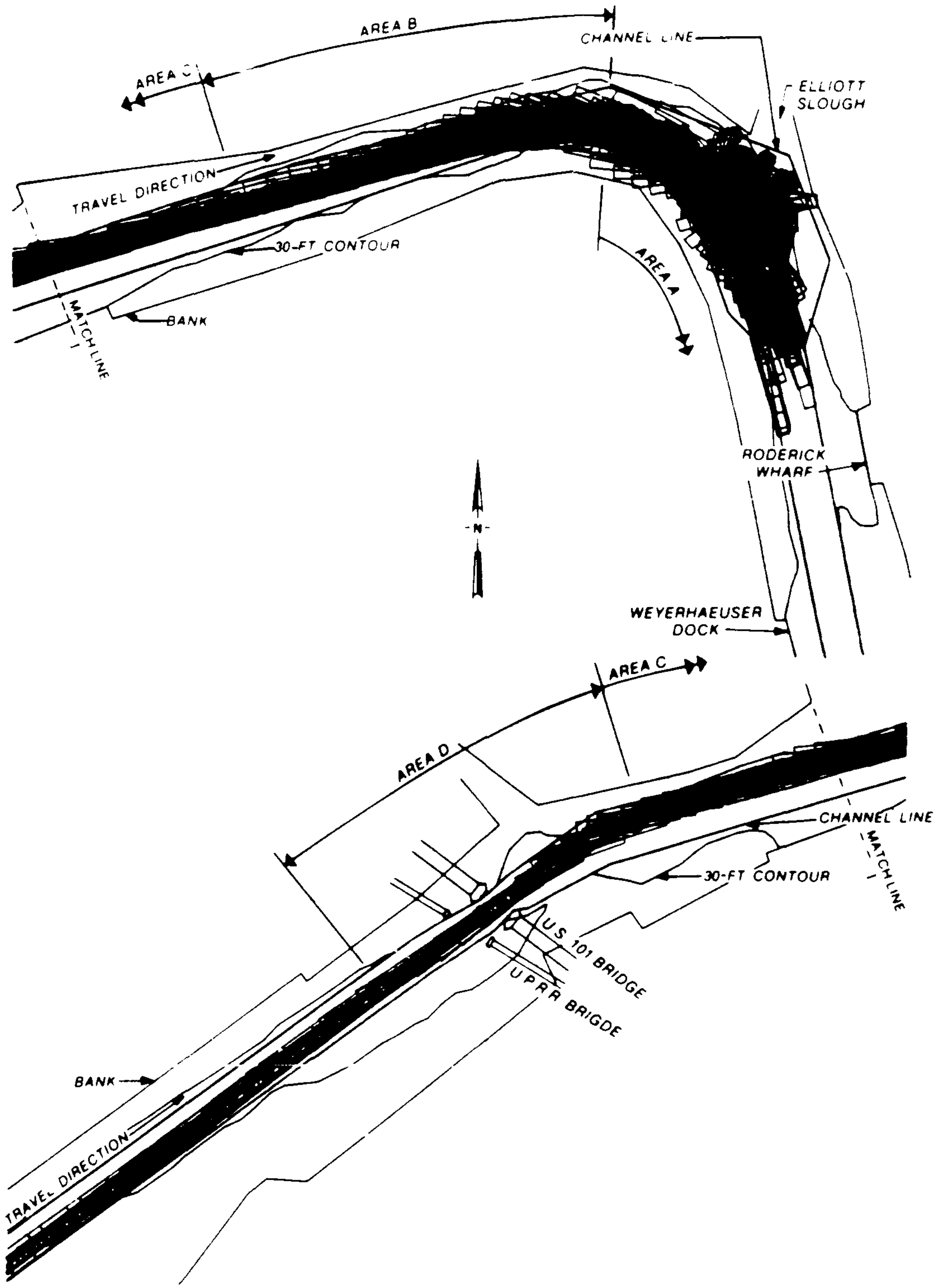

Figure 23. Composite inbound pilot runs, recommended channel, inner region

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Outer Region

Conclusions

40. The tests clearly showed that the primary problem experienced by the pilots was drifting beyond the channel edge on the outside of the bends. Within the range tested, the width of the straight reaches did not have a significant impact on pilot performance.

Recommendation

41. The design recommendation for the outer region is to construct a 100-ft widener on the outside of the first two bends (outbound). Figure 15 details these wideners. Transitions from the wideners can be used to return the channel to the current 350-ft width. No other widening is required.

Inner Region

Conclusions

42. The tests indicate that it will be feasible to navigate the larger, deeper draft lumber ships in the inner part of the harbor with the railroad bridge modification in place. The proposed turning basin size and location should be adequate for the size of ship tested. The proposed channel design requires some modifications for optimization. Some existing channel safety impediments should be removed.

Recommendations

43. The south side of the channel just above the bridges does not need to be widened as far to the south as is proposed. Figure 21 shows details of the recommendations. The channel between the bridge and the turning basin should be widened to 350 ft. Figure 21 shows a channel widener in the 90-deg bend which is recommended for safer maneuvers into the turning basin. The recommended removal of the former Standard Oil dock should allow safer maneuvers also. Removal of the old bridge piers above the two bridges and relocation of the channel marker in the same area should make the passage through the bridges safer.

Table 1

Grays Harbor Outer Region Pilot Simulation Runs

Test No.	Date	Time	Channel (Width × Depth) ft	Timber Ship (Length × Beam) ft	Draft ft	Tidal Advantage ft
1	7/22/86	1140	350 × 30	535 × 80	34.0	4.0
2	7/22/86	1502	350 × 38	625 × 100	36.5	4.0
3	7/22/86	1553	350 × 38	625 × 100	36.5	4.0
4	7/23/86	0815	350 × 30	535 × 80	34.0	4.0
5	↓	0909	400 × 38	625 × 100	36.5	2.5
6	↓	0956	400 × 38	↓	↓	↓
7	↓	1046	350 × 38	↓	↓	↓
8	↓	1259	350 × 38	↓	↓	↓
9	↓	1428	400 × 38	↓	↓	↓
10	↓	1516	400 × 38	↓	↓	↓
11	↓	1608	350 × 30	535 × 80	34.0	4.0
12	9/16/86	1245	350 × 38	625 × 100	36.5	2.5
13	↓	1318	400 × 38	625 × 100	36.5	2.5
14	↓	1352	350 × 38	625 × 100	36.5	2.5
15	↓	1430	350 × 38	625 × 100	36.5	2.5
16	↓	1529	350 × 30	535 × 80	34.0	4.0
17	↓	1604	400 × 38	625 × 100	36.5	2.5
18	↓	1306	350 × 30	535 × 80	34.0	4.0

Table 2

Grays Harbor Inner Region Pilot Simulation Runs

Test No.	Date	Time	Channel (Width × Depth) ft	Timber Ship (Length × Beam) ft	Draft ft	Tidal Advantage ft
1	10/01/86	0953	200 × 30	535 × 80	34.0	6.0
2		1041			34.0	
3		1112			34.0	
4		1152			34.0	
5		1355			17.0	
6		1426			17.0	
7		1455			17.0	
8		1629			17.0	
9	10/02/86	0837	250 × 36	625 × 100	36.5	2.5
10		0925			36.5	
11		1016			19.0	
12		1051			19.0	
13		1187			19.0	
14		1207			19.0	
15		1343			36.5	
16		1420			36.5	
17		1452			19.0	
18		1517			19.0	
19		1534			36.5	
20		1615			36.5	
21		1649	200 × 30	535 × 80	34.0	6.0
22		1717	200 × 30	535 × 80	34.0	
23	10/03/86	0854	250 × 36	625 × 100	19.0	
24		0917				
25		0946				
26		1016				
27		1043				
28		1116				
29		1145				
30		1216				
31	10/09/86	1309			36.5	2.5
32		1340			36.5	
33		1413			36.5	
34		1443			36.5	
35		1546			19.0	
36		1633			19.0	
37		1708	200 × 30	535 × 80	34.0	6.0
38		1734	200 × 30	535 × 80	34.0	6.0
39	10/10/86	0817	250 × 36	625 × 100	36.5	2.5
40	10/10/86	0847	250 × 36	625 × 100	36.5	2.5

(Continued)

Table 2. (Concluded)

Test No.	Date	Time	Channel (Width × Depth) ft	Timber Ship (Length × Beam) ft	Draft ft	Tidal Advantage ft
41	10/10/86	0915	200 × 30	535 × 80	34.0	6.0
42		1102	200 × 30	535 × 80	34.0	6.0
43		1153	250 × 36	625 × 100	19.0	2.5
44		1231	250 × 36	625 × 100	19.0	2.5
45		1314	250 × 36	625 × 100	19.0	2.5

Table 3

Means of Channel Edge Clearances, Ft

Test Channel	Moon Island to Crossover Reaches		Crossover to South Reaches		South Reach	
	Port	Starboard	Port	Starboard	Port	Starboard
			Mean Clearance			
Existing	152	109	98	158	116	156
Proposed	119	150	92	188	129	171
Suggested	157	78	94	136	107	141
Recommended*	153	113	121	138	121	127
			Mean Minimum Clearance			
Existing	66	−19	8	47	50	89
Proposed	15	17	2	96	58	83
Suggested	64	−61	9	20	38	42
Recommended*	62	27	28	33	50	35

* Clearances were obtained using proposed and suggested channel runs imposed on recommended channel alignment.

Table 4

Means of Channel Edge Clearances, Outbound Runs, Ft

Test Channel	Area A Port	Area A Starboard	Area B Port	Area B Starboard	Area C Port	Area C Starboard	Area D Port	Area D Starboard
				Mean Clearance				
Existing	169	-50	4	96	25	69	72	31
Proposed	155	14	36	62	56	52	87	56
Recommended*	162	30	80	74	79	146	72	70
				Mean Minimum Clearance				
Existing	1	-168	-57	-21	-73	11	22	-6
Proposed	-23	-98	-52	-23	-39	-29	31	-17
Recommended*	-24	-67	15	0	46	90	31	35

* Clearances were obtained using proposed channel runs superimposed on recommended channel alignment.

Table 5

Means of Channel Edge Clearances, Inbound Runs, Ft

Test Channel	Area A Port	Area A Starboard	Area B Port	Area B Starboard	Area C Port	Area C Starboard	Area D Port	Area D Starboard
				Mean Clearance				
Existing	–	–	–	–	–	–	11	92
Proposed	124	85	47	41	–50	145	41	109
Recommended*	142	93	95	69	36	172	46	93
				Mean Minimum Clearance				
Existing	–	–	–	–	–	–	–31	31
Proposed	–58	–146	–18	–16	–103	67	–40	47
Recommended*	–54	–142	–10	2	–1	135	–7	43

* Clearances were obtained using proposed channel runs superimposed on recommended channel alignment.